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Title:

"Simple settings towards fuel economy in disc harrowing"

(Project sponsored by the Programme Supporting the Modernising of Portuguese Agriculture and Forestry-PAMAF-8.140)

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Summary:

In the last twenty years there has been an increment in tractor power, weight, tyre dimensions, as well as four-wheel-drive generalisation and the adoption of electronics, making easier the handling of the tractor and the control of the implement.

These rapid changes, in most case, have not been met with adequate training of tractor drivers who tend to adopt settings and driving solutions from the their previous tractors, which were more limited in power and traction, largely of the two-wheel-drive type.

The above stated and the present requirement for the reduction in costs and soil damage, brings back the need to re-appreciate some of the common practices.

This paper reports the results of field tests performed under real agricultural conditions, using a four-wheel-drive tractor and trailed disc harrow combination, in four different settings:

Treatment I - Tractor with full ballast (including liquid ballast); disc harrow at a wide angle between gangs; engine at the rated speed; the highest gear selected in the transmission at which the work can 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);

Treatment II - The same as treatment I, but no liquid ballast;

Treatment III - No liquid ballast ; angle between disc gangs as in treatment I ; engine set at 80% of the rated speed ; the same gear as in treatment I, or a higher gear selected, if possible;

Treatment IV - The same as in treatment III, but reducing the gang angle of the harrow, in order to allow effectively a shift up in the gear box.

Results are shown in terms of fuel consumption and work rate.

From settings I to IV, there is a general trend towards a reduction in fuel consumption per unit of area worked, without compromising the work rate and soil tilth.

Key Words: Disc harrow; Tractor Performance; Fuel Consumption .

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Abstract

In the last twenty years there has been an increment in tractor power, weight, tyre dimensions, as well as four-wheel-drive generalisation and the adoption of electronics, making easier the handling of the tractor and the control of the implement.

These rapid changes, in most case, have not been met with adequate training of tractor drivers who tend to adopt settings and driving solutions from the their previous tractors, which were more limited in power and traction, largely of the two-wheel-drive type.

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Introduction

In the dry farming system of Southern Portugal, offset disc harrows are very popular among farmers. Within the usual three years rotation of winter wheat / winter wheat / sunflower crops, disc harrows are used as primary and secondary cultivation tools.

After ploughing, usually in the previous fall, spring seedbeds are obtained by cultivating the furrows with two passes of a disc harrow, followed by a roller to provide a firm, level surface for precision drilling.

Seedbed preparation for the winter crops, in lighter soils, is obtained disc harrowing first to open the stubble, followed by a second pass to established the required tilth, ending with the roller.

Disc harrowing, being part of a traditional tillage system, has been the object of a research program comparing traditional tillage with reduced and no-tillage systems in terms of crop yield (Carvalho and Basch, 1996) and soil conservation (Basch and Carvalho, 2000).

A three years research project, sponsored by the Portuguese Agriculture Ministry, has recently been completed, aiming to study the relative weight of different variables present in the dynamics of the interaction tractor-soil-disc harrow under real working conditions.

Within this framework, Peça *et al.* (1998), reported a small decrease in the fuel consumption per hectare, when the tractor pulling the harrow included ballast, explained by the expected reduction in tyre slip.

Peça *et al.* (1998) and Serrano *et al.* (1998), have shown that tractor drivers adopting a gear up , throttle down technique will get fuel economy, at no expense of the work rate.
In this soil conditions, it has also been reported (Serrano *et al.*, 2000) that operating at a reduced angle between disc gangs, and at a higher working speed, it is possible to obtain better working rates and fuel economy, with no significant difference in soil tilth.
Field observation revealed that tractor drivers usually operate tractors at full ballast, and set up their working conditions from the widest possible angle between disc gangs, even if that leads to pull the harrow at a relatively slow speed.
To emphasise that in these dry farming soils the above practices should be questioned, a set of field tests were devised, from which conclusions may be drawn, step by step towards the best final solution.

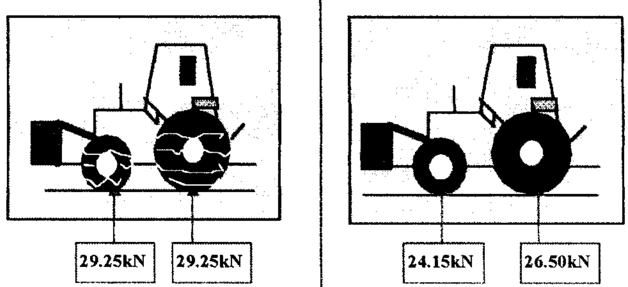
Objectives

The objective of this work was to evaluate in terms of fuel consumption and work rate, a tractor and two trailed disc harrows, in the following work settings:
Treatment I - Tractor with full ballast (including liquid ballast); disc harrow at a wide angle between gangs; engine at the rated speed; the highest gear selected in the transmission at which the work can 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);
Treatment II - The same as treatment I, but no liquid ballast;
Treatment III - No liquid ballast ; angle between disc gangs as in treatment I ; engine set at 80% of the rated speed ; the same gear as in treatment I, or a higher gear selected, if possible;
Treatment IV - The same as in treatment III, but reducing the gang angle of the harrow, in order to allow effectively a shift up in the gear box.

Material and Methods

Tractor

A four-wheel-drive, 59kW (DIN), Massey-Ferguson 3060 Datatronic tractor, was used in the field trials. 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.
Front ballast weights and 75% volume water filled front and rear tyres, gave static axle loads presented in the left side of figure 1. Static axle loads without liquid ballast are presented in the right side of figure 1.



Tyre (Dimension)	Load/tyre (kN)	Inflation pressure (kPa)
13.6R24	14.6	124
16.9R34	14.6	100

Tyre (Dimension)	Load/tyre (kN)	Inflation pressure (kPa)
13.6R24	12.1	100
16.9R34	13.2	76

Figure 1- Static axle loads and tyres inflation pressure
with and without ballast.

Tractor tyre inflation pressure was adjusted according to tyre static vertical load following tyre manufacturer manual.

Implement
Two trailed type medium-weight offset disc harrows with the following specifications 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

Data Acquisition System - DAS
Information provided by the TPM is volatile. To overcome this limitation a portable computer based record system was developed (Peça *et al.,* 1998) which deviates the signals from the tractor TPM sensors as well as the information from a 50 kN load cell based pull measuring system.
With the input of the rolling radius of the tyre, and the working width of the implement the DAS is able to produce the following performance parameters: average slip, drawbar pull, drawbar power, work rate, and fuel consumption per hectare.

Soils
In an effort to match field trials to real farming conditions, the opinion of the farmer, regarding the actual soil conditions for harrowing as well as the final result as an adequate seedbed, were taken into account at each test site.
Test sites were chosen according to the utilisation of the disc harrow in primary and secondary cultivation systems (table 2).

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

Site	Type of soil	Initial Condition of the soil	Moisture content, d.b. (%)	Soil dry density (kg/m^3)
1-Outeiro	Loam	Undisturbed	7.3	1351
1-Outeiro	Loam	Harrowed	5.4	1408
2-Louseiro	Loamy-sand	Ploughed	12.6	1427
2-Louseiro	Loamy-sand	Ploughed +harrowed	11.8	1592
3-Casão	Sandy-clay-loam	Ploughed	8.1	1456
3-Casão	Sandy-clay-loam	Ploughed +harrowed	10.6	1533

Test Procedure
In each treatment measurements were taken, in 80 to 100 m runs, with 2 replications.
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.
Samples of soil were taken to measure the moisture content, the soil dry bulk density and to determine the soil type.

Results and Discussion
A synthetic presentation of the results results is shown in table 3.

The discussion will be focused on the overall fuel consumption per hectare and on the overall time required per hectare to perform two consecutive harrow passes on each test site, as follows:
Site 1 - A first pass over undisturbed soil, for crop residues disposal, followed by a second pass to improve soil tilth;
Site 2 and 3 - A first pass over ploughed soil followed by a second pass to improve soil tilth.
Assuming that the overall fuel consumption per hectare and the overall time required per hectare are both 100% in treatment 1 (the most common settings among tractor operators), then figure 2 shows the relative results found for the other three treatments.

Table 3- Average results from 2 replications at each treatment.

Site and Soil Condition	Treatment	Harrow	α (°)	Gear	n (rpm)	V_a (km/h)	d (cm)	s (%)	T (kN)	P (kW)	W_r (ha/h)	C_{ha} (L/ha)
1 Undisturbed	I	20 Discs	46	17th	2168	7,28	0,11	3	13,71	27,72	1,50	8,72
	II		46	17th	2167	7,16	0,11	5	14,43	28,70	1,47	9,09
	III		46	19th	1679	6,68	0,11	5	14,88	27,61	1,38	7,80
	IV		37	21th	1664	8,05	0,11	5	12,01	26,86	1,71	6,28
1 Harrowed	I	20 Discs	46	17th	2152	7,05	0,18	9	14,76	28,88	1,59	9,32
	II		46	17th	2167	7,06	0,18	9	15,51	30,42	1,60	9,49
	III		46	19th	1656	6,58	0,18	7	15,46	28,25	1,49	7,95
	IV		37	21th	1668	7,97	0,14	8	13,90	30,77	1,80	7,17
2 Ploughed	I	20 Discs	37	13th	2109	6,10	0,21	9	16,83	28,51	1,29	14,03
	II		37	13th	2155	6,25	0,21	8	16,28	28,27	1,33	12,62
	III		37	13/15th	1656	5,24	0,21	9	16,10	23,42	1,11	10,26
	IV		33	15th	1668	5,81	0,21	9	15,31	24,71	1,23	9,40
2 Plow+Harrow	I	20 Discs	33	15th	2052	7,12	0,18	7	14,62	28,91	1,51	11,97
	II		33	15th	2151	7,37	0,18	10	14,41	29,49	1,56	11,19
	III		33	15th	1666	5,74	0,18	10	14,12	22,51	1,22	9,47
	IV		28	15/17th	1682	6,33	0,18	11	13,00	22,85	1,34	9,21
3 Ploughed	I	20 Discs	41	13th	2154	6,26	0,21	9	15,76	27,42	1,32	13,20
	II		41	13th	2143	6,16	0,21	9	17,24	29,49	1,30	12,37
	III		41	13th	1663	4,83	0,21	12	16,68	22,38	1,02	10,65
	IV		37	15th	1656	5,69	0,21	10	16,03	25,32	1,21	9,96
3 Plow+Harrow	I	20 Discs	33	13th	2146	6,27	0,20	9	15,13	26,34	1,38	11,69
	II		33	13th	2158	6,39	0,20	7	13,44	23,88	1,41	10,25
	III		33	15th	1675	5,88	0,20	10	13,51	22,05	1,29	8,42
	IV		28	15th	1679	5.96	0,20	9	12,16	20.12	1,29	8,19
1 Undisturbed	I	24 Discs	50	15th	2183	6,03	0,14	8	19,25	32,25	1,51	10,11
	II		50	15th	2163	5,81	0,14	11	18,91	30,54	1,45	10,16
	III		50	17th	1696	5,41	0,14	6	18,95	28,46	1,35	8,98
	IV		34	19th	1661	6,60	0,13	4	15,66	28,70	1,67	6,87
1 Harrowed	I	24 Discs	50	15th	2167	5,91	0,17	12	19,99	32,82	1,58	10,41
	II		50	15th	2150	5.58	0,17	16	20,18	31,31	1,50	10,94
	III		50	17th	1664	5,15	0,17	12	20,21	28,91	1,38	9,27
	IV		34	19th	1683	6,62	0,17	9	16,13	29,65	1,77	7,21
2 Ploughed	I	24 Discs	37	13th	1905	5,46	0,22	10	18,88	28,62	1,41	11,70
	II		37	13th	2061	5,77	0,22	13	18,74	30,03	1,49	12,19
	III		37	13th	1655	4,67	0,22	14	19,83	25,71	1,21	10,35
	IV		28	15th	1648	5,59	0,21	10	15,99	24,83	1,46	8,59
2 Plow+Harrow	I	24 Discs	30	13th	2167	5,77	0,17	14	15,84	25,40	1,48	11,92
	II		30	13th	2151	6,32	0,17	7	15,25	26,78	1,62	8,81
	III		30	13th	1688	4,93	0,17	12	15,11	20,71	1,27	8,54
	IV		26	15th	1671	5,75	0,18	11	13,96	22,31	1,48	7,87
3 Ploughed	I	24 Discs	39	13th	2064	5,80	0,22	13	18,90	30,44	1,49	11,72
	II		39	13th	2057	5.78	0.22	12	19,08	30,63	1,49	11,03
	III		39	13th	1652	4,66	0,22	14	18,47	23,91	1,20	10,11
	IV		28	15th	1674	5,77	0,20	11	14,92	23,93	1,51	7,60
3 Plow+Harrow	I	24 Discs	30	13th	2158	6,32	0,20	8	14,73	25,84	1,69	10,57
	II		30	13th	2157	6,43	0,20	6	13,89	24,81	1,72	8,61
	III		30	15th	1671	5,84	0,20	10	13,74	22,28	1,56	7,38
	IV		26	15th	1667	5.92	0,19	8	13,13	21,59	1,58	6,71

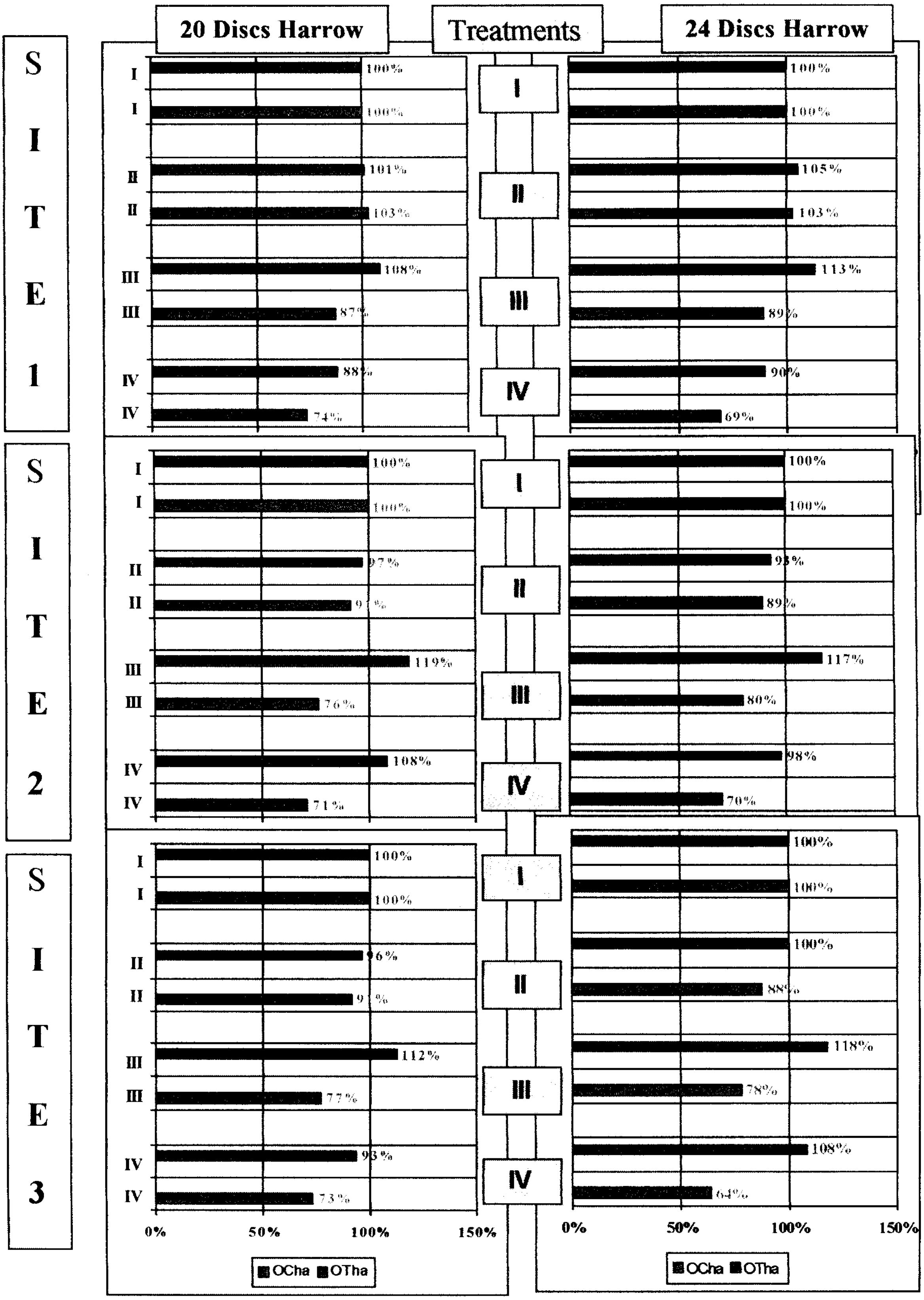


Figure 2- Overall Consumption per hectare (OCha) and Overall Tillage Time per hectare (OTha) relative to Treatment I, in percentage.

Where: α-Angle between disc gangs (degrees);

n-Engine speed under load (rpm);	T- Drawbar pull (kN);
V_a-Actual forward speed (km/h);	P-Drawbar power (kW);
d-Working depth (cm);	W_r- Work rate (ha/h);
s- Slip (%);	C_{ha}- Fuel Consumption per hectare (L/ha).

In sites 2 and 3 where the harrow was used after the plough, it can be seen that tractor performance is better, in terms of fuel economy and work rate, with no liquid ballast (treatment 1 to treatment 2). However, when the tractor used for ploughing and harrowing are the same, the effect of no liquid ballast on the heavy draught required by the plough should be also considered.
In site 1, where the harrow performed primary and secondary cultivation, the presence of liquid ballast shows marginal savings. To avoid soil compaction, as well as to permit a more efficient general utilisation of the tractor, the common and indiscriminate use of liquid ballast should be questioned.

Figure 2 clearly shows that by simply shifting up and throttling down, (treatment 2 to treatment 3) there are substantial savings in terms of fuel, however at an expense of the working rate. This drawback can be overcome by simply reducing the angle between the disc gangs and shifting up even further (treatment 3 to treatment 4), providing that the quality of the work, the safety and comfort of the operator are kept unaffected.

Conclusions

Within the tillage systems where the disc harrow performs either primary or secondary cultivation, in the light soils of Southern Portugal, tractor drivers should always question about the advantage of liquid ballast on their tractors.
Tractor drivers, should contemplate to set, by test prior to work, the right combination of transmission gear, throttle and gang angle within the limits of the quality of the work and the safety of the operation, since substantial savings in fuel at no expense of the work rate may be obtained.

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