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Title:

"The effect of gang angle of offset disc harrows in work rate and fuel consumption"

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

Authors:

Serrano, J. M., Peça, J. O.(*), Pinheiro, A., Carvalho, M., Nunes, M., Ribeiro, L. and Santos, F.

Universidade de Évora, Departamento de Engenharia Rural, Núcleo da Mitra, Apartado 94, 7002-554 ÉVORA – PORTUGAL, Tel. 351-266 76 08 50, Fax-351-66-71 11 89, E-mail: jmrs@uevora.pt

Summary:

In offset disc harrows, the angle between gangs may be changed to meet the field conditions. Tractor drivers usually use an angle close to maximum, increasing power requirements and therefore limiting the forward speed and, consequently, the work rate.
The objective of this work is to evaluate, in terms of work rate and fuel consumption per hectare, the effect of working faster with a lower angle between disc gangs.
A trailed type medium-weight offset disc harrow (20 discs of 610mm diameter) was used, pulled by a four-wheel-drive tractor. A portable computer based record system was used to collect engine speed, actual forward speed, slip, fuel consumption and draught force.
Field and working conditions were characterised by soil type and moisture, implement working width and depth.
Higher work rates and lower values of fuel consumption per hectare can be attained with no visible difference in soil tilth, by operating the disc harrow at a lower angle between disc gangs and shifting up in the tractor gear box.
Tractor drivers, particularly those with tractors equipped with performance monitors should contemplate to set, by test prior to work, the right combination of gang angle and forward speed within the limits of quality of the work and the safety of the operation.

Key Words: Disc harrow; Gang angle; Work rate; Fuel consumption per unit area.

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Abstract

In offset disc harrows, the angle between gangs may be changed to meet the field conditions. Tractor drivers usually use an angle close to maximum, increasing power requirements and therefore limiting the forward speed and, consequently, the work rate.
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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 path 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).
Recently 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-disc harrow, under real working conditions imposed to the system.

This study made an evaluation of different paired relations of tractor weight/implement width, building up a matched set (Peça *et al.*, 1998) and the effect of "gear-up, throttle down" on fuel consumption per hectare cultivated, and work rate (Peça *et al.*, 1998; Serrano *et al*., 1998).
Although the angle between gangs in offset disc harrows may be changed to meet field conditions, observation showed that tractor drivers usually use an angle close to the maximum, increasing draught requirements and therefore limiting the forward speed and, consequently, the work rate. If an acceptable result in terms of soil tilth or buried crop residues could be attained at a lower angle between disc gangs, then what advantage could be taken in terms of fuel economy and work rate?

Purpose

The objective of this work was to study, in the specific soil conditions present in Southern Portuguese agricultural, the effect of working faster with a disc harrow at a reduced gang angle, in terms of work rate, fuel consumption per hectare and distribution of dry soil aggregates.

Material and Methods

A trailed type medium-weight offset disc harrow with 20 discs of 610mm diameter was pulled by a four-wheel-drive tractor equipped with a portable computer based record system to collect engine speed, actual forward speed, slip, fuel consumption and draught force.
Field and working conditions were characterised by soil type and moisture, implement working width and depth.
Results were evaluated in terms of work rate, fuel consumption per hectare and distribution of dry soil aggregates.

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. It was equipped with 13.6R24 and 16.9R34 tyres, respectively in the front and rear axles.
Front ballast weights, and 75% volume water filled front and rear tyres, gave static axle loads presented in figure 1.
Tractor tyre inflation pressure was adjusted according to tyre static vertical load following tyre manufacturer manual.

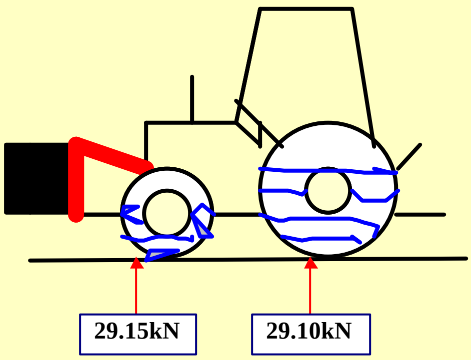
Implement

A trailed type medium-weight offset disc harrow with the following specifications was used in the field trials (Table 1).

Table 1- Trailed disc harrow.

Disc diameter (mm)	Number of discs	Static weight per disc (daN/disc)	Disc spacing (mm)	Max. working width (mm)
610	20	65	230	2350

Figure 1- Static axle loads and tyre inflation pressure.



Tyre (Dimension)	Load/tyre (kN)	Inflation pressure (kPa)
13.6R24	14.58	152
16.9R34	14.55	124

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 power, work rate and fuel consumption per hectare.

Soils

Two fields with different soil types were selected:

- Site 1 - Outeiro - a loam/clay loam;
- Site 2 - Louseiro.- a loamy sand.

These fields, located in private farms, have typical soils of the region of Évora (Alentejo, Southern Portugal).

Soil conditions in site 1 (Figure 2) was a sheep grazed sunflower stubble, left undisturbed over autumn. The test was done in January, when the moisture content, in the 200 mm top layers averaged 16.5% (d.b.).

Soil conditions found in site 2 (Figure 3) resulted from a 30 cm depth ploughing done in March, a week before the date of the test. The average value of moisture content in site 2 was 6.6% (d.b.).

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

Figure 2 –Field experiments in Site 1- Outeiro.

Figure 3 –Field experiments in Site 2- Louseiro.

Test Procedure

At the maximum angle between disc gangs, and throttle set to 1800 rpm (82% of the rated speed), a preliminary test was run, with the operator shifting up in the gear box, step by step, to reach the highest speed in which he was able to perform the work with the required quality, within his standards of comfort and safety and without engine overcharge (no significant decrease in engine speed). This test was repeated at a lower angle between disc gangs at which, according to the operator's judgement, no apparent change in the quality of the work in the soil was visible.

After the combinations of throttle, gear and gang angle were set, the actual measurements were taken, at each angle between disc gangs, in 50 m runs, with 4 replications.

The average depth of the mobilised soil layer was obtained from at least 20 values, along the 50 m 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 12 direct measurements across each 50 m harrowed path.

A mean weight diameter (MWD) method (White, 1993) was used for determining the distribution of dry soil aggregates. A total of 8 MWD tests were done for each angle between disc gangs, two in each 50 m run. The soil sample of each MWD test, after being let to air dry for 2 days, was sieved through nine sieves of the following mesh sizes: 2mm ; 4.75mm ; 9.5mm ; 19mm ; 25mm ; 38.1mm ; 50mm ; 75mm ; 100mm.

Results

A synthetic presentation of the results is shown in tables 2 and 3, and in figure 4.

Table 2- Average results from 4 replications at each angle between disc gangs in site 1.

Angle between disc gangs (degrees)	n (rpm)	Gear	V_a (km/h)	d (cm)	s (%)	T (kN)	P (kW)	**W_r (ha/h)**	**C_{ha} (L/ha)**
46	1670	15th	5.80	19.4	7	18.68	30.11	**1.21**	**11.69**
37	1681	17th	6.90	18.8	5	15.16	29.05	**1.46**	**9.96**

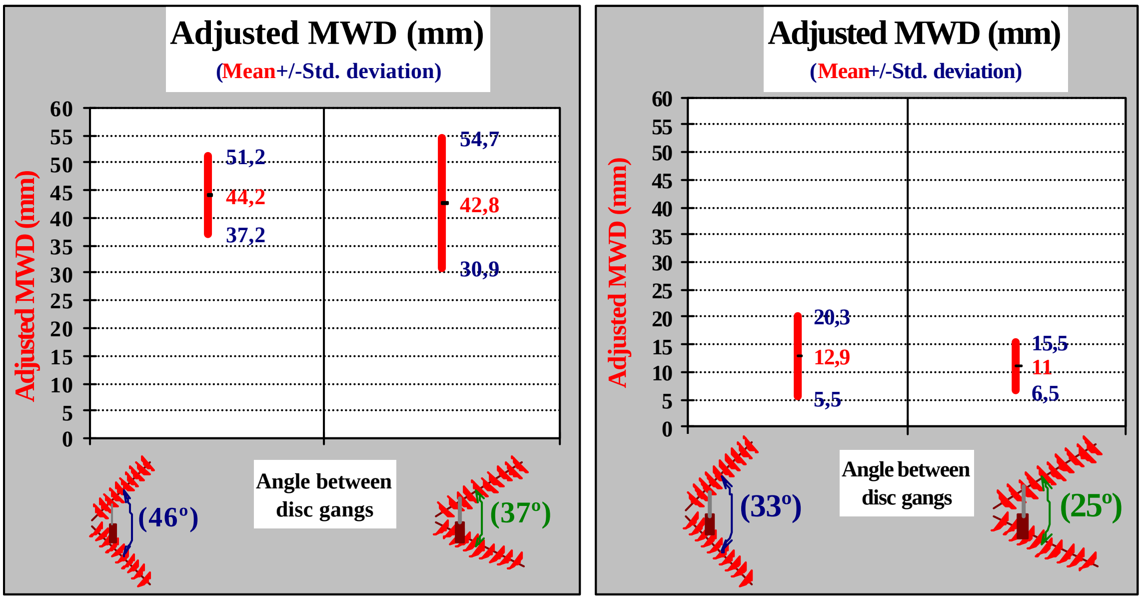
Table 3- Average results of 4 replications at each angle between disc gangs in site 2.

Angle between disc gangs (degrees)	n (rpm)	Gear	V_a (km/h)	d (cm)	s (%)	T (kN)	P (kW)	**W_r (ha/h)**	**C_{ha} (L/ha)**
33	1712	13th	4.93	27.0	16	15.28	21.67	**1.09**	**11.06**
25	1626	17th	6.61	27.0	11	11.79	20.91	**1.46**	**9.34**

Where:

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

Figure 4- Adjusted MWD from 8 samples at each angle between disc gangs, in site 1 (left) and in site 2 (right).



Discussion

Although a complete picture of the soil-disc harrow interaction is beyond the scope of this work, it is assumed that the relevant variables to explain the results are the working speed through the soil and the gang angle, determined by the angle between the line of travel and the plane containing the circular edge of the disc.

When the angle between gangs was reduced by 9 degrees in site 1 and by 8 degrees in site 2, resulted in a reduction of approximately 4 degrees in the gang angle. At the same time the speed was increased from 5.8 to 6.9 km/h (19%) in site 1 and from 4.9 to 6.6 km/h (35%) in site 2.

Singh *et al*. (1978) reported that a reduction in the gang angle and an increment in the working speed caused opposite effects on the working depth of a disc harrow. He produced evidence showing that a reduction in the gang angle, at a constant working speed, resulted in shallow work, whereas increasing working speed, at a constant gang angle, produced deeper work. This opposite effects may have resulted in a working depth practically unchanged in the present experiments.

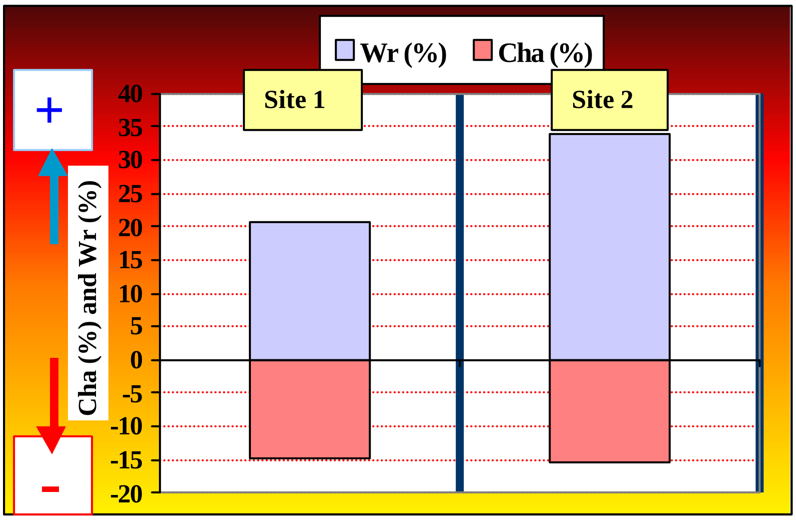
The nature of soil reaction to discs (on harrow discs) was well explained by McCreery and Nichols (1956) and McCreery (1959) revealing why the draught force required to pull one disc, at a constant depth, decreased as the disc angle approaches a certain value. Beyond this angle, draught is kept fairly constant, showing, however, an expected tendency to rise, what is clearly shown by Gordon (1941) on plough discs, at 0 degrees of inclination angle.

Gordon (1941) also reports an increase in the draught force, at a slightly accelerated rate, with the working speed, for a standard plough disc at constant depth.

From the above stated concerning the pertinent factors for draught on discs, and within the range of gang angles used (close to the maximum), its is believed that the reduction in the draught as a result of closing the angle between disc gangs, prevailed over the increase in the draught due to a higher working speed.

Since the variation imposed to the angle between disc gangs kept the working width of the harrow, practically unchanged, then closing the harrow and moving faster led to a higher work rate (Figure 5). Furthermore, the lower angle between disc gangs, requiring a lower draught force, per unit of working width, and allowing better traction efficiency to the tractor, made possible a better overall efficiency, translated in a reduction in the fuel consumption per hectare (Figure 5).

Figure 5 – Variation, in percentage, in the work rate and fuel consumption per hectare, after reducing the angle between gangs and working faster.



In each test site, the soil tilth left behind the disc harrow, was virtually the same regardless the angle tested, something that the subsequent MWD tests for the distribution of aggregates were able to confirm (Figure 6).
Possibly, in these lighter soil, the higher working speed, pulverising the soil, acted to compensate for the less effective cutting action at the lower disc angle.

Figure 6 – Soil aggregates from a MWD test in Site 1: top, at maximum angle between gangs (46 degrees); bottom, at a lower angle (37 degrees) and working faster.

Conclusions

Higher work rates and lower values of fuel consumption per hectare can be attained with no visible difference in soil tilth, by operating the disc harrows at a lower gang angle and shifting up in the tractor gear box.

Tractor drivers, particularly those with tractors equipped with performance monitors should contemplate to set, by test prior to work, the right combination of gang angle and forward speed within the limits of the quality of the work and the safety of the operation.

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