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The Effect of Gang Angle of Offset Disc Harrows on Soil Tilth, Work Rate and Fuel Consumption

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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 was to study, in the specific soil conditions present in Southern Portuguese agriculture, the effect of working with a disc harrow at a reduced gang angle and at a higher forward speed, in terms of work rate, fuel consumption per hectare and distribution of dry soil aggregates.

A trailed-type medium-weight offset disc harrow (20 discs of 610 mm 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.

Higher work rates and lower values of fuel consumption per hectare were attained, with no visible difference in soil tilth, by operating the disc harrow at a lower angle between disc gangs and shifting up to a higher gear ratio whilst maintaining engine speed.

Tractor drivers, particularly those with tractors equipped with performance monitors should consider setting, by preliminary tests prior to the main field work, the right combination of gang angle and forward speed within the limits of quality of the work and the safety of the operation.

1. Introduction

In the dry farming system of Southern Portugal, offset disc harrows are very popular among farmers. Within the usual 3 yr 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. 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.

A previous survey conducted by the authors among 26 farmers within the region of Évora (Alentejo, Southern Portugal), revealed average values of power input of 3·0 kW and 3·5 kW per disc, respectively, for 610 and 660 mm disc diameter, in light soils (Serrano João, 2002).

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

Recently, a 3 yr research project was approved by the Portuguese Agriculture Ministry to study the relative

Notation

C_{ha} fuel consumption per unit of cultivated area, kg ha^{-1}
C_s specific fuel consumption, g kW^{-1} h^{-1}
η_m efficiency of tractor transmission, dimensionless
η_t tractive efficiency, dimensionless
$\mathfrak{J}$ draught per unit of implement width, kN m^{-1}

weighing of different variables present in the dynamics of the interaction between the tractor, soil and disc harrow, under real working conditions imposed on 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 João *et al.*, 1998).

2. Materials and methods

A trailed-type medium-weight offset disc harrow with 20 discs of 610 mm 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 theoretical work rate, fuel consumption per unit of cultivated area and distribution of dry soil aggregates.

2.1. *Tractor*

A four-wheel drive, 59 kW (DIN) tractor, was used in the field trials. This tractor is factory equipped with a tractor performance monitor, which, among other functions, provide relevant information such as: engine speed, actual forward speed, wheel 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 Table 1. Tractor tyre inflation pressure was adjusted according to tyre static vertical load following tyre manufacturer manual.

2.2. *Implement*

A trailed-type medium-weight offset disc harrow with the following specifications was used in the field trials (Table 2).

2.3. *Data acquisition system*

Information provided by the tractor performance monitor is volatile. To overcome this limitation, a portable computer-based recording system was developed, which analyses the signals from the tractor performance monitor sensors as well as the information from a 50kN load cell based, pull measuring system (*Fig. 1*).

The adopted solution consists of a portable computer equipped with a data acquisition board capable of up to eight single-ended channels, 12-bit resolution and 100 000 samples s^{-1} 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. A signal provided by the manual operation of the 'timing active' function switch of the tractor performance monitor at the end of each 50 m run, triggers the program to save the data. The corresponding file is named after the date hour information provided by the personal computer. The data was analysed in the laboratory using a spreadsheet.

Table 1
Static axle loads and tyre inflation pressure

Tyres	*Dimension*	*Axe load, kN*	*Inflation pressure, kPa*
Front	13·6R24	29·15	152
Rear	16·9R34	29·10	124

Table 2
Trailed disc harrow

Disc diameter, mm	*Number of discs*	*Static weight per disc, N*	*Disc spacing, mm*	*Max. working width, mm*
610	20	650	230	2350

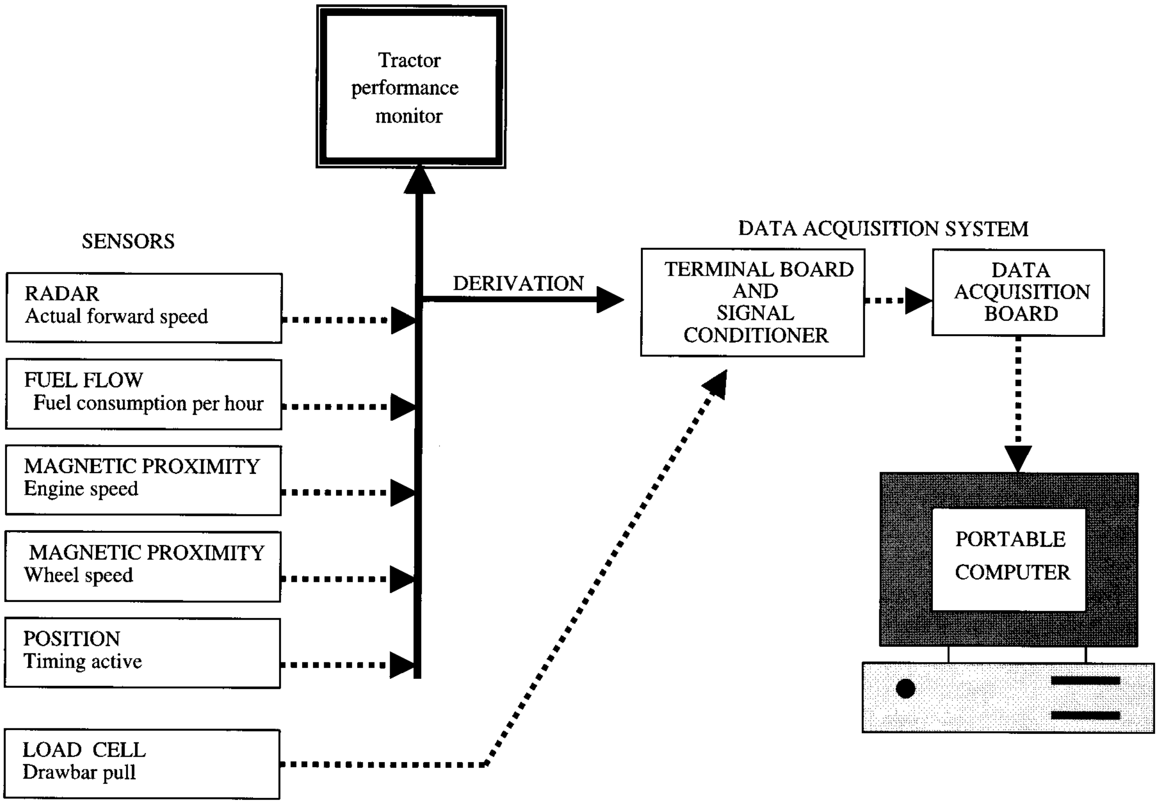

Fig. 1. The data acquisition system (DAS)

Table 3
Soil conditions: average results in the 200 mm top layers

Location	*Soil composition*			*Classification*	*Moisture content (d.b.), %*	*Bulk density, kg/m^{-3}*	*Cone index, kPa*
	Clay, %	*Silt, %*	*Sand, %*				
Site 1, Outeiro	28	29	43	Loam/clay loam	16·5	1431	2987
Site 2, Louseiro	16	10	74	Loamy sand	6·6	1328	66

With the input of the rolling radius of the tyre, and the working width of the implement, the data acquisition system is able to produce the following performance parameters: average wheel slip, drawbar power, work rate and fuel consumption per hectare.

2.4. *Soils*

Two fields with different soil types were selected:

(a) site 1 at Outeiro, a loam/clay loam; and
(b) site 2 at Louseiro, a loamy sand.

These fields, located on private farms, have typical soils of the region of Évora. Soil conditions in each site are presented in Table 3.

The soil condition at site 1 was a sheep-grazed sunflower stubble, left undisturbed over autumn. Soil conditions found at site 2 resulted from a 300 mm depth ploughing done in March, a week before the date of the test.

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.

2.5. *Test procedure*

At the maximum angle between disc gangs, and throttle set to 1800 min^{-1} (82% of the rated speed), a preliminary test was run, with the operator shifting to a higher gear, 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 two combinations of throttle, gear and gang angle were set, defining two treatments, the actual measurements were taken in 50 m runs, with four replications.

The average depth of the mobilised soil layer was obtained from at least 20 values, along the 50 m run, each value being, 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. Soil samples, two for each 50 m run, were collected and sieved, after being let to dry for 2 days.

3. Results and discussion

Table 4 shows the average results from four replications at each angle between disc gangs, at sites 1 and 2. Tables 5–8 describe the soil variation and analysis of variance, in terms of MWD, between replications and treatments in both sites.

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.

Table 4
Average results from four replications at each angle between disc gangs for sites 1 and 2

Angle between disc gangs, deg	*Engine speed underload, min^{-1}*	*Gear*	*Forward speed, km h^{-1}*	*Working depth, m*	*Wheel slip, %*	*Drawbar pull, kN*	*Drawbar power, kW*	*Theoretical work rate, ha h^{-1}*	*Fuel consumption per unit of cultivated area, l ha^{-1}*
Site 1, Outeiro									
46	1670	15th	5·80	0·194	7	18·68	30·11	1·21	11·69
37	1681	17th	6·90	0·188	5	15·16	29·05	1·46	9·96
Site 2, Louseiro									
33	1712	13th	4·93	0·270	16	15·28	21·67	1·09	11·06
25	1626	17th	6·61	0·270	11	11·79	20·91	1·46	9·34

Table 5
Adjusted MWD at each angle between disc gangs at site 1

Angle between disc gangs, deg	*Mean, mm*	*Standard deviation, mm*
46	44·2	7·4
37	42·8	12·7

Table 7
Adjusted MWD: at each angle between disc gangs at site 2

Angle between disc gangs, deg	*Mean, mm*	*Standard deviation, mm*
33	12·9	7·9
25	11·1	4·8

Table 6
Adjusted MWD: analysis factorial ANOVA for replications (1–8) and angles (46 and 37°) at site 1

K value	*Source*	*Degrees of freedom*	*Sum of squares*	*Mean square*	*F value*	*Prob*
1	Replication	7	759·037	108·434	1·0048	0·4976
2	Angle	1	8·702	8·702	0·0806	
−3	Error	7	755·418	107·917		
	Total	15	1523·157			

Coefficient of variation: 23·87%; difference is not significant (NS).

Table 8
Adjusted MWD: analysis factorial ANOVA for factor replications (1–8) and angles (33 and 25°) at site 2

K value	*Source*	*Degrees of freedom*	*Sum of squares*	*Mean square*	*F value*	*Prob*
1	Replication	7	375·124	53·589	0·8881	
2	Angle	1	41·926	41·926	0·6948	
−3	Error	7	422·409	60·344		
	Total	15	839·459			

Coefficient of variation: 53·37%; difference is not significant (NS).

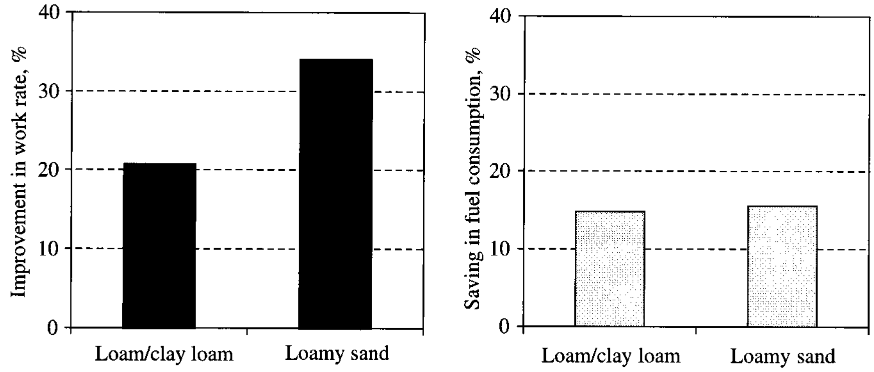

Fig. 2. Variation, after reducing the angle between gangs and shifting to a higher gear, in: theoretical work rate ■ and fuel consumption per unit of cultivated area □

At sites 1 and 2, the reduction in the gang angle was approximately 4°. At the same time, the speed was increased from 5·8 to 6·9 km h^{-1} (19%) at site 1 and from 4·9 to 6·6 km h^{-1} (35%) at 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. These 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° 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 pertinent factors stated above for draught on discs, and within the range of gang angles used (close to the maximum), it 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 on the angle between disc gangs kept the working width of the harrow practically unchanged, closing the harrow and moving faster may lead to higher work rate (*Fig. 2*).

Fuel consumption per unit of cultivated area can be related to the pertinent variables from the tractor engine and transmission, implement and soil, and tyre and soil interactions, by

$$C_{ha} = \frac{C_s \Im}{360\eta_m \eta_t} \quad (1)$$

where: C_{ha} is the fuel consumption per unit of cultivated area in kg ha^{-1}; C_s is the specific fuel consumption in g kW^{-1} h^{-1}; η_m is the efficiency of tractor transmission; η_t is the tractive efficiency; and $\Im$ is the draught per unit of implement width in kN m^{-1}.

In Eqn (1), $(\eta_m\, \eta_t / C_s)$ represents the overall efficiency of the conversion of fuel into useful work.

Fig. 2 shows, for both sites, a reduction of 15% in the fuel consumption per unit of cultivated area, as a result of closing the angle between discs gangs and working at a higher forward speed. This value is, however, less than the 20% reduction measured in the draught force per unit of working width, suggesting a slight reduction in the overall efficiency.

At each test site, the soil tilth left behind the disc harrow, was virtually the same regardless of the angle tested, something that the subsequent MWD tests for the distribution of aggregates were able to confirm since no significant differences in the MWD between gang angles were found (Tables 5–8).

Possibly, in these lighter soils, the higher working speed, pulverising the soil, acted to compensate for the less effective cutting action at the lower disc angle.

5. Conclusions

In the light soils tested, higher work rates and lower values of fuel consumption per unit of cultivated area were attained with no visible difference in soil tilth, by operating the disc harrows at a lower gang angle and shifting to a higher gear in the tractor.

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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