

Sensors and Electronic Control Unit for Optimize Rotary Harrow Soil Tillage Operation



Francesco Marinello, Filippo Pegoraro and Luigi Sartori

Abstract Agricultural operations, and in particular tillage practices, can have a relevant influence on environmental as well as economic sustainability. The possibility of optimizing tillage operation is thus interesting in order to allow not only improvement of soil structure and cloddiness, but also better management of residues, minimization of soil disturbance and of vertical translocation of organisms, and reduction of energetic costs. The present paper reports on a research study carried out for the development of a power harrow equipped with sensors, which quantify the working depth, the height and load on the levelling bar. Data are managed by an ECU (Electronic Control Unit) which provides a feedback signal for the optimization of the working depth and the position of the levelling bar. Field tests were carried out in order to validate the effectiveness of the approach. For the scope, specific analyses were concurrently carried out to validate the proposed solution, including fuel consumption, power absorption and soil analyses (sieving, three-dimensional roughness and permanence time in the rotary harrow chamber). Finally, it is shown how the proposed approach can help maximization of the constancy of working depth and avoidance of excessive tillage intensity.

Keywords Rotary harrow · Sensors · Optimized tillage · Soil cloddiness

1 Introduction

Soil tillage is a basic and important component of agricultural production technology, playing a key role not only for the preparation of the desired seedbed, but also to manage crop residues, control weeds, alleviate compaction, optimize soil temperature and moisture regimes, improve aeration and in general soil physical structure

F. Marinello · L. Sartori (✉)

Department of Land, Environment, Agriculture and Forestry (TESAF), University of Padova,
Viale Dell'Università 16, 35020 Padova, Italy
e-mail: luigi.sartori@unipd.it

F. Pegoraro

Alpego Spa, Via Giovanni E Giuseppe Cenzato 9, 36045 Almisano, Italy

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A. Coppola et al. (eds.), *Innovative Biosystems Engineering for Sustainable Agriculture, Forestry and Food Production*, Lecture Notes in Civil Engineering 67,
https://doi.org/10.1007/978-3-030-39299-4_57

(Lal 1991). Therefore, soil tillage operations play a key role not only from the agronomic but also from the economic point of view. Indeed, following the current and increasingly important attention to costs reduction at farm level, an optimization of the tillage operations can usefully help a simplification of the interventions and an overall reduction of related investment along with an increase of sustainability (Borsato et al. 2018). Precision agriculture techniques applied to soil processes are, at present, still relegated to an experimental stage although it is clear their importance for agricultural production in containing costs and protecting environmental resources. In such direction, there is the possibility of effective developments related to the ability to combine new approaches in tillage operations with precision agriculture practices. In particular there is a growing attention on the possibility to adjust the tillage intensity on the basis of specific crop requirements or as a function of soil characteristics variability. This is specifically interesting in the case of seedbed preparation, where often happens that the operator applies excessive soil tilling, with a consequent excessive refinement of the soil which is not of help to the plants and conversely might worsens the soil structure. The possibility of continuously monitoring a tillage operation, through implementation of specific sensing devices (Dubini et al. 2017) and resulting in an automatic correction of the implement's settings holds a high potential in terms of energy and time optimization and eventually costs reduction (Pezzuolo et al. 2017). The efforts of the research community have already produced interesting results, with direct or indirect systems proposed both for static or dynamic monitoring. Marinello et al. (2015) proposed a method based on the infrared Kinect depth camera; Moret-Fernández et al. (2016) achieved 3D reconstruction of soil aggregates through photogrammetry; Ajdadi et al. (2016) developed a machine vision approach for classification of 2D images; Kayad et al. (2019) tested implementation of RFID antennas for assessment of soil or residue movements following harrowing operations. The present work proposes indirect estimation of soil cloddiness through specific application of load cells on levelling bar.

2 Materials and Methods

Rotary harrows, driven by the power take-off, are implements which exhibit a relatively high flexibility of use, operating on soils to break the clods into small aggregates even in the case of difficult conditions, as for instance in the case of tenacious soils with very big clods, or when seedbed preparation is needed immediately after the primary tillage. On the other hand, such implements are typically characterized by high energy costs, not too high working speeds or working capacity and, depending on the types, a tendency to produce excessive reduction of aggregates with negative effects on soil structure and even erosion risks.

The implement used for the present research is a commercial rotary harrow (by Alpego spa), equipped with sensors which allow on the go monitoring of harrowing conditions and intensity. More specifically, it is equipped with:

- an ultrasonic sensor (namely S1) which measures the position of the levelling bar (see Fig. 1a, b);
- an second ultrasonic sensor (namely S2) which reveals the position of the roller (see Fig. 1a, c);
- two load cells at the end of the levelling bar and measuring the pressure of harrowed soil contained in the refining chamber and pressing on the bar itself (Fig. 1a, d).

The implemented power harrow is equipped with 10 rotors (300 rpm, 250 mm in height) and a spiral roller; the leveling bar is fixed on the roller with independent

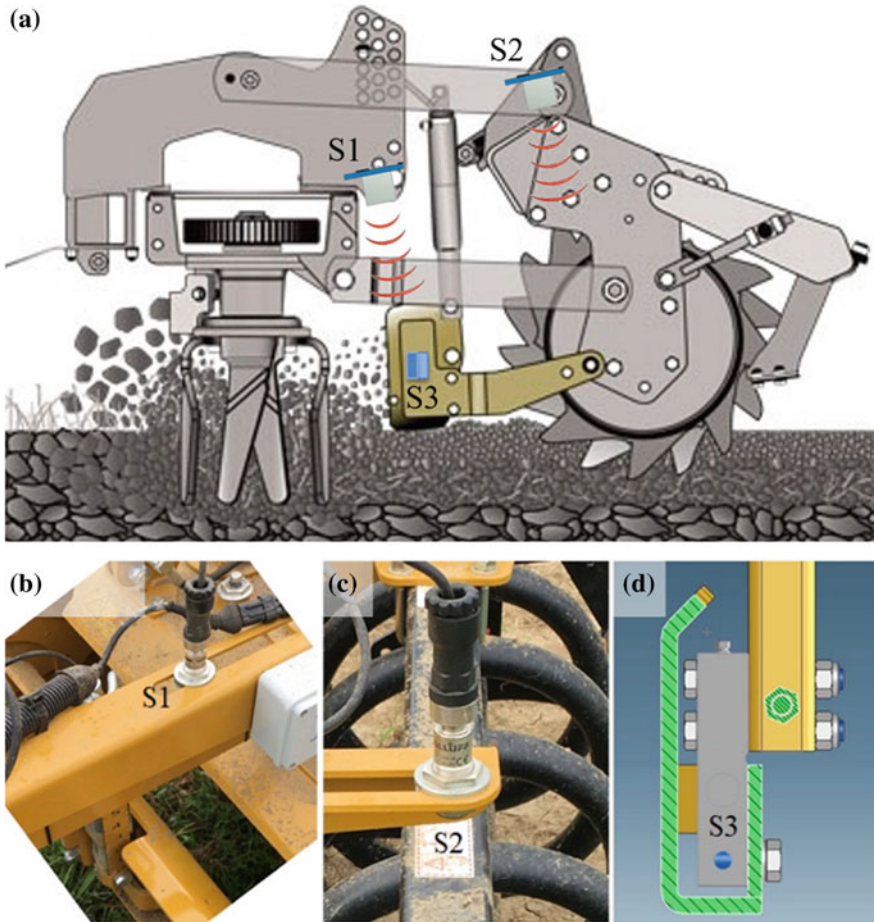


Fig. 1 On the top a schematic view of a harrowing machine and positioning of the two ultrasonic sensors (S1 and S2) and load cells (S3). On the bottom line a zoom on the levelling bar (b) and roller (c) height ultrasonic sensors. In d, schematic representation of the localization of the load cells (S3)

Table 1 Main characteristics of soil in the trials

Soil characteristics	Unit	Quantity
Sand (0.02–2.0 mm)	gg ⁻¹	0.51
Silt (0.002–0.02 mm)	gg ⁻¹	0.33
Clay (<0.002 mm)	gg ⁻¹	0.16
Dry bulk density	Mg m ⁻³	1.6
Skeleton	%	<1

adjustment. The overall working width is 2.35 m, with a typical working speed of 4–6 km/h and a working capacity of about one hectare per hour.

Research activities were carried out at the experimental farm of the University of Padova (45.3464 N, 11.9531 E), having a medium-silty texture, with an average 15% humidity in the first 10 cm (see Table 1).

A full set of parameters was collected during experiments, as described in the following. Traction force required for the operation of the harrow was measured with a dynamometer applied between the towing tractor and the tractor operating the harrow (Fig. 2a).

Time and distance for each operation was collected, allowing calculation of average forward speed along with tillage feed (i.e. the distance between two subsequent passages of rotor tools) (Fig. 3). A vibrating sieving system was applied in order to characterize soil aggregate size distribution after harrowing in the 0–5 cm soil layer. The volume of soil accumulated in the refining chamber and released with the lifting of the tool (Fig. 2b) was three-dimensionally reconstructed and quantified through implementation of a Kinect sensor (Marinello et al. 2015). A series of RFID tags inserted on cork capsules was positioned in the ground before the passage of the machine (Fig. 4c) and localized after harrowing by means of a RFID sensitive antenna: the relative shift was used in order to quantify the permanence of the clods in the refinement chamber, as described by Kayad et al. (2019). The horizontal soil resistance was measured in terms of load on the leveling bar through installed load cells (see S3 in Fig. 1), while ultrasonic sensors (S1 and S2 in Fig. 1) allowed definition of relative height of the leveling bar from the ground and of working depth.

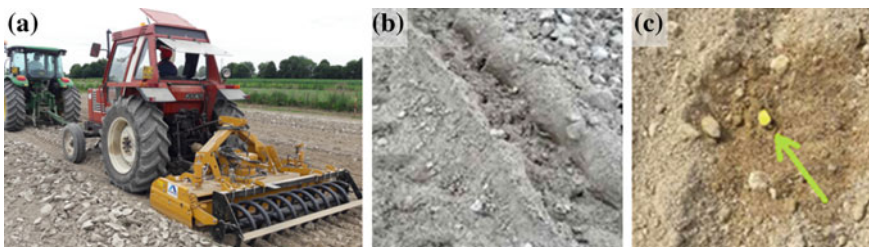


Fig. 2 The two tractors working approach for estimation of traction force (a); soil accumulated in the refining chamber (b) and RFID tags used to quantify permanence of soil within the mixing chamber (c)

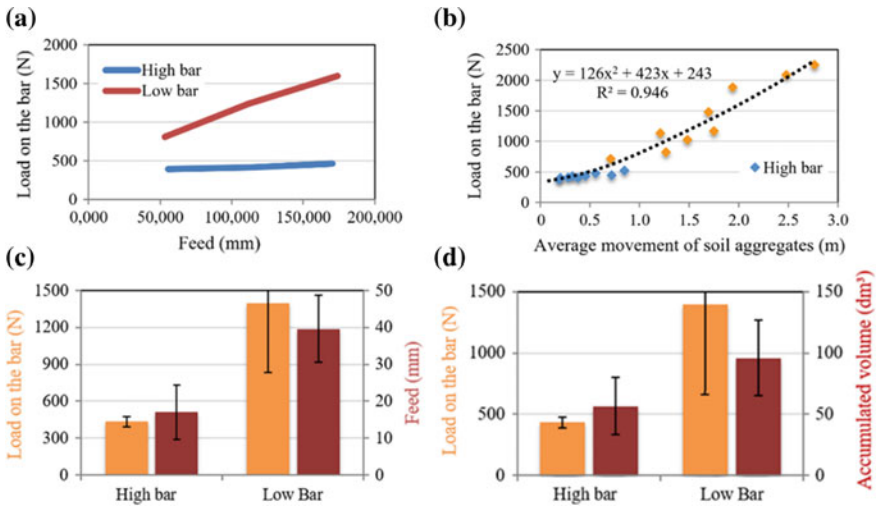


Fig. 3 On the top row: **a** effect of the bar position and cutting range on load on the bar; **b** relation between soil aggregates movements and load on the bar; on the bottom row average values for feed (c) and accumulated volume (d) at different bar positions

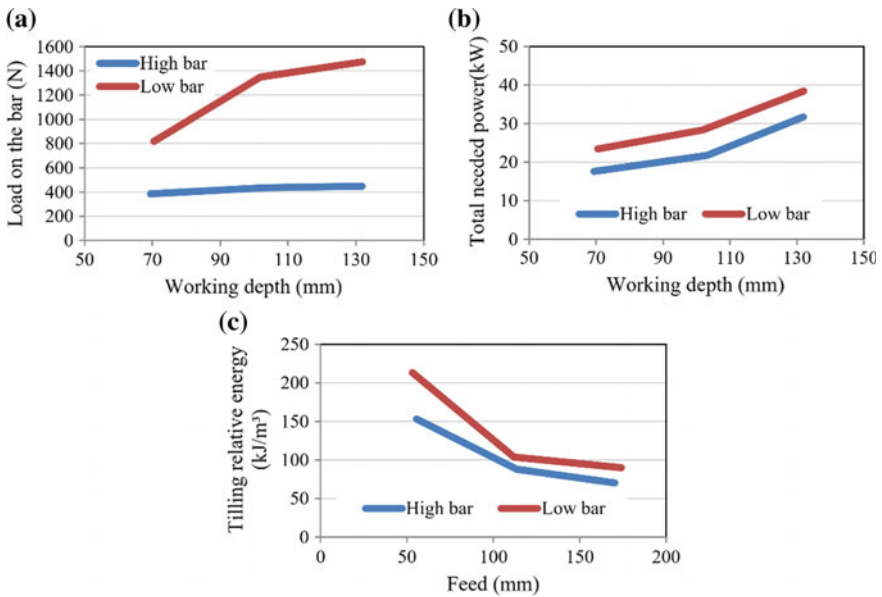


Fig. 4 Effect of working depth on load detected at the bar (a), total needed power (b) and tilling relative energy (c)

Experimental tests were carried out considering three different forward speeds (2, 4 and 6 km/h), three different working depths (7, 10 and 13 cm) and two leveling bar relative heights (8 and 14 cm).

3 Results

Experimental tests confirmed the relevance and the influence of the leveling bar on the quality of the harrowing operation both in terms of agglomerate size and needed tilling energy. The following table is a summary of the test results on the bar (Table 2).

The levelling bar in the low position causes the greatest accumulation of clods on its surface and therefore, compared to the high position, an increased permanence of the aggregates in the mixing chamber, in the near proximity of the rotors. This explains the higher load revealed when the bar is lowered during tillage, as highlighted by Fig. 3: load almost doubles (from ~800 to ~1600 N) when increasing the speed from 2 to 6 km/h (corresponding to tillage feeds respectively from 55 to 170 mm). On the other hand, when the levelling bar is raised, no soil aggregates are pressing on the bar and the detected load is almost constant (~400 N).

The effect is also confirmed by the second graph in Fig. 3, in which the load values on the bar are reported for the 18 tests performed as a function of the average displacement of soil aggregates, estimated by means of RFID tags spread over the ground before the tests. The graph reports data in different colors differentiated by the position of the bar itself. It is clear that in the raised bar position, soil aggregates have an average permanence inside the mixing chamber which varies on average between 0.5 and 1.5 s (corresponding to an average shift of clods ranging between 0.2 and 0.9 m), while the same parameter triples when the bar lays in the lower position, taking on average between 1.5 and 4.5 s (0.7–2.8 m). Averaging data, an almost linear trend can be recognized, better fitted by a second degree function: such relation is useful, as it can be implemented in order to use the load on the bar as a feedback control for the average permanence time of soil aggregates into the mixing chamber and eventually as a feedback control for the final size of aggregates themselves. This can be more clearly appreciated with the first histogram representation, which reports the direct correlation between the load exerted on the bar and the volume of soil retained in the mixing chamber as well as with the second histogram which reports the average amount (volume) of soil kept by the leveling bar within the mixing chamber during tillage (Fig. 3): in both cases the parameters assume reduced values when the bar is raised, reversing the tendency when the bar is lowered. Similarly, variations in working depth also influence the total amount of tilled soil, producing different loads on the bar, evident in particular with the bar lowered, with loads ranging from 800 N in the case of low working depth (70 mm) up to 1500 N in the case of high working depth (130 mm), as shown in Fig. 4.

It is worth noting that working conditions influencing the final size of soil aggregates and thus the load on the levelling bar, have also an effect on power need to carry out the tillage operation. Such effect is confirmed by the graphs in Fig. 4: both

Table 2 Main results from the experimental tests

Levelling bar position	Speed (km/h)	Feed (mm)	Bar height (mm)	Load on bar (N)	Clods size (mm)	Traction power (kW)	Power at the PTO (kW)	Overall power (kW)	Energy (Wh/m ³)
High	2	55.5	142.6	393.3	15.1	1.49	18.3	19.8	42.5
	4	113.5	143.1	414.1	18.7	3.53	19.5	23.0	24.4
	6	170.4	143.0	460.0	22.3	6.31	21.8	28.1	19.5
Average				422.5	18.7	3.78	19.86	23.64	28.8
Low	2	53.2	86.3	806.8	11.5	1.51	24.6	26.1	59.2
	4	111.9	87.1	1236.6	11.5	4.65	23.2	27.8	28.8
	6	174.0	87.3	1597.2	12.1	8.75	27.4	36.1	24.9
Average				1213.6	11.7	4.97	25.05	30.02	37.6

of them show how at different feeds as well as at different working depths, the lower leveling bar position produces a net increase of total needed power ranging between 25 and 30%.

Trends and correlations highlighted between field tests parameters (such as cloddiness or power consumption) and indices monitored by the sensors installed on the rotary harrow are useful for a management optimization of the implement. Indeed, controlling the working depth and the position of the leveling bar (singularly or concurrently) allows the user to control the size of soil aggregates after tilling in compliance with the agronomic needs and optimizing at the same time absorbed power and energy consumption.

4 Conclusions

The present research reports the first results obtained using after a rotary harrow equipped with specific transducers which allow on the go quantification of the working depth, of the relative height and of the load on the levelling bar. Analyses gave evidence of correlations between different analyzed parameters, opening up to the possible definition of transfer function which can be implemented for optimization of tillage operations in terms of minimization of implemented tillage power, while targeting suitable soil aggregates size.

Thus, the proposed rotary harrow sensorization and analysis approach can maintain constant the working condition (in terms of depth and clods dimensions) and avoid excessive tillage intensity.

Acknowledgements The research has been partially supported by PRIN 2015 2015KTY5NW “Optimization of operating machinery through the mission profile analysis for a more efficient agriculture”.

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