Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/sjar

Spanish Journal of Agricultural Research 2008 6(2), 182-188
ISSN: 1695-971-X

The forward speed effect on draught force required to pull trailed disc harrows

J. M. Serrano* and J. O. Peça

ICAM. Rural Engineering Department. University of Évora. 7002-554 Évora. Portugal

Abstract

Discs harrows are the most commonly used tillage implements in Portugal. A review of available information shows that the forward speed effect in draught requirements of trailed disc harrows is not clear. This paper gives the results of field trials with trailed disc harrows, performed in the field in different soils. The results show that draught force tends to increase with forward speed and that this relationship is almost linear at speeds between 3 and 9 km h^{-1}.

Additional key words: draught, prediction, real field trials.

Resumen

Efecto de la velocidad de avance en el esfuerzo de tracción demandado por las gradas de discos

Las gradas de discos son los aperos de preparación del suelo más comunes en Portugal. La revisión de la información disponible muestra que el efecto de la velocidad de avance en el esfuerzo de tracción demandado por las gradas de discos no está perfectamente clarificado. En este artículo se presentan los resultados de ensayos realizados con gradas de discos en condiciones reales, en diferentes tipos del suelo. Los resultados ponen en evidencia que el esfuerzo de tracción aumenta con la velocidad y demuestran que esta relación es aproximadamente lineal, entre 3 y 9 km h^{-1}.

Palabras clave adicionales: ensayos en condiciones reales, esfuerzo de tracción, predicción.

Introduction[1]

Draught is the force required to propel an implement in the direction of travel (ASAE, 1994a). A convenient measure of disc draught is the specific draught per unit implement width (Al-Janobi and Al-Suhaibani, 1998) or the projected specific draught per unit cross-sectional area of the tilled zone, correspond to implement draught divided by the rectangular area defined by the cutting width and the depth of disc penetration (Sommer *et al.*, 1983).

The availability of draught requirement data of tillage implements is important in selecting suitable tillage implements for a particular farming situation. Farm managers and consultants use draught and power requirement data of tillage implements in specific soil types to determine the size of tractor required. Therefore, predictions of implement draught requirement are important for tractor selection and implement matching (Al-Janobi and Al-Suhaibani, 1998).

Factors that directly affect the required draught of trailed disc harrows are related to soil characteristics and conditions (texture, mainly clay content, moisture and previous cultivation), the disc harrow (their working width, number of discs, the vertical weight $disc^{-1}$ and disc type) or its use (the angle between disc gangs and forward speed).

These factors regulate the working depth, which, according to the literature, is directly related to the required draught.

* Corresponding author: jmrs@uevora.pt
Received: 18-08-07; Accepted: 15-04-08.

[1] Abbreviations used: a, b, c, C_i (regression coefficients), d (working depth, cm), d.b. (dry basis), F_i (dimensionless soil texture adjustment parameter), Re (draught per unit cross-sectional area of the tilled zone, N cm^{-2}), SD (standard deviation), T (draught, N), TPM (tractor performance monitor), v_r (forward speed, km h^{-1}), α (angle between disc gangs, degrees), β_i (regression coefficients), $\Im$ (draught per unit of implement width, kN m^{-1}).

In Portugal disc harrows are used for primary soil tillage, seedbed preparation, weed control and for the incorporation of manure, fertiliser and herbicides. This article reviews information on the draught of disc harrows systems. The complex dynamics of the interaction disc-soil has led innumerable research teams to do research under controlled conditions with the aim of isolating some of the factors.

Many studies measured draught and the power requirements of tillage implements under various soil conditions. The ASAE Standards (1994b) give mathematical expressions for draught and power requirements for tillage implements in several soils as part of the ASAE Data D497. As many changes in tillage equipment have occurred in the last 20 years an update of the ASAE data on draught and power requirements is required (Al-Janobi and Al-Suhaibani, 1998).

The general model used to estimate the requirements of draught force of a tillage implement is presented by Ramp and Siemens (1990), Harrigan and Rotz (1994, 1995), and Siemens (1996). It represents the interaction with speed through a quadratic function.

Implement width, operating depth and speed are the factors which affect draught of a tillage implement. Draught also depends on soil conditions and the geometry of the tillage implements (Upadhyaya *et al*., 1984, cited by Al-Janobi and Al-Suhaibani, 1998). The effect of speed on implement draught per unit width or cross-sectional area of the tilled zone depends on soil and implement type (Al-Janobi and Al-Suhaibani, 1998).

Morera (1993) and Béltran (1995) investigated the effect of speed on draught with three most commonly used Spanish tillage implements: a mouldboard plough, a chisel plough and trailed disc harrows. The data dispersion they obtained hindered establishment of a direct correlation among the physical parameters. However, they verified a trend to increased draught with speed in all the implements, for speeds between 3.2 to 7.5 km h^{-1}.

Other authors consider draught as a function of working speed and working depth. Grisso *et al*. (1994 and 1996) developed field trails with a trailed disc harrow in «tandem», with a 4.9 m working width, with 46 cm diameter discs in front and 43 cm diameter discs at the back and a gang angle of 15 degrees. This study had, as independent variables, working depth and working speed and also considered soil parameters. Depths of 5.1, 7.6 and 12.7 cm and speeds of 4.8, 6.4 and 9.7 km h^{-1} were tested. The regression equation that led to these results, from a sandy clay loam, in primary soil tillage, showed the interaction of depth and speed on the draught (T, in N), with a correlation coefficient of 0.97.

Glancey (1990, cited by Glancey *et al*., 1996) presents the most complex equation of all, in the literature, as it considers multiple regression, with the interaction of depth and speed, and both variables as quadratic functions of the draught per unit implement width ($\mathfrak{I}$, in N mm^{-1} or kN m^{-1} for trailed disc harrows).

Al-Janobi and Al-Suhaibani (1998) used the same equation as Glancey (1990, cited by Glancey *et al*., 1996) and presented the coefficients from field tests in loamy sand soils, in primary soil tillage, with a moisture content (d.b.) of 9.5%, with a trailed 36 disc harrow with discs, of 51 cm of diameter. This study had as independent variables working depth and working speed, and tested depths of 10, 15 and 20 cm and six speeds, between 3 and 9 km h^{-1}).

An appreciation of the proposals does not allow confirmation of the effect of working speed on draught to be established perfectly, once it oscillates among linear variations, described by the equations of Summers *et al*. (1986), Ramp and Siemens (1990), Grisso *et al*. (1994), Harrigan and Rotz (1994, 1995) and Siemens (1996). Draught variations are sharper each time with increased speed (quadratic equations), as supported by the work of Morera (1993), Beltran (1995) and Al-Janobi and Al-Suhaibani (1998).

Some of these models formulate draught in trailed disc harrow as functions of working depth and working speed but they correspond to specific application domains in terms of characteristics of the implement and the soil. They do not clarify the probable interaction between working speed and working depth.

Grisso *et al*. (1994, 1996) presents a contradiction, as it is the only report that considers a negative effect of speed on draught. The restricted scope for application of the equation stands out when the same one produces indications of decreased draught from 20 cm depth, which does not have a reasonable physical justification.

However, the results of the equation of Al-Janobi and Al-Suhaibani (1998) tend to underestimate the required draught, which was recognized by the authors, compared with the model of Harrigan and Rotz (1994). This model predicts, that for a working depth of a trailed disc harrow of 20 cm, there are linearly increased values of drawbar pull per unit implement width between 6.5 and 8 N mm^{-1}, when the forward speed was varied between 3 and 9 km h^{-1}, respectively, while the model

Table 1. Tractors and disc harrows used in the field trails

Site	Tractor model (maximum power, DIN)	Disc harrows model	Number of discs	Disc diameter (mm)	Static weight disc^{-1} (N disc^{-1})
1	Massey-Ferguson 3060 (59kW)	Herculano (HPR 20-24")	20	610	65
2	Massey-Ferguson 3060 (59kW)	Herculano (HPR 20-24")	20	610	65
3	Massey-Ferguson 3060 (59kW)	Herculano (HPR 24-24")	24	610	61
4	Massey-Ferguson 3060 (59kW)	Herculano (HPR 24-24")	24	610	61
5	Massey-Ferguson 3650 (110kW)	Galucho (GSM 24-28")	24	711	83
6	Massey-Ferguson 6180 (88kW)	Fialho (FI/RTF 24-26")	24	660	81
	Massey-Ferguson 3060 (59kW)	Herculano (HPR 20-24")	20	610	65
7	Massey-Ferguson 3680 (134kW)	Galucho (GLHR 36-26”)	36	660	97

of Al-Janobi and Al-Suhaibani (1998) estimates values of between 3 and 6 N mm^{-1}, at the same speed interval, for a working depth of 20 cm.

Forward speed is one of the most common factors in the available literature. The specific objective of this study was to evaluate the effect of forward speed on draught under real working conditions.

Material and Methods

Tractors and implements

Table 1 gives the main specifications of the tractors and offset disc harrows which were used in the field trails.

Data acquisition system

The adopted solution, described by Serrano *et al.* (2003), is based on a portable computer which deviates the signals from the TPM (tractor performance monitor) sensors (radar and position sensor) as well as the information from a 50 kN load cell based pull measuring system. A data acquisition board and a terminal board provide the appropriate connection and the voltage excitation for the load cell. A Lab VIEW application was developed to control data acquisition.

Soils

The fields, which were located on private farms, had soils with typical characteristics of the Évora Region (Alentejo, Southern Portugal). Seven sites were selected, five in undisturbed soils (1- C. Mira; 2- Oliveiras; 3- Fitojardim; 4- Louseiro; 5- Outeiro) and two in mobilised soils (6- Barrocal; 7- Selmes).

Table 2 summarizes soil characteristics at the trail sites and gives soil condition; soil composition (clay, silt and sand) and soil moisture content (calculated on a dry weight basis), based on samples collected during the tillage experiments from the top 200 mm layer. It also indicates the medium value of the bulk density and of the index cone for the same soil layer.

Table 2. Soil conditions at the trail sites

Site	Soil condition	Soil composition			Moisture content (dry basis, %)	Bulk density (kg m^{-3})	Cone index (kPa)
		Clay (%)	Silt (%)	Sand (%)			
1	Primary tillage	68	13	19	11.5	1,567	1,678
2	Primary tillage	73	10	17	19.0	1,679	1,015
3	Primary tillage	70	10	20	10.0	1,518	1,109
4	Primary tillage	69	17	14	13.0	1,623	1,390
5	Primary tillage	49	23	28	12.0	1,351	2,987
6	Secondary tillage	56	11	33	11.0	1,498	68
7	Secondary tillage	29	20	51	12.0	1,383	694

Test procedure

The field trials were conducted under real work conditions of agricultural production and used farmers' equipment. This restricted the methodology used. Prior to each experiment, various settings were tested concerning the angle between disc gangs, and combinations of engine regime-gear selection that would allow different forward speeds. Three forward speeds were used between 3.5 and 9.0 km h^{-1}. The maximum forward speed at each site was selected taking into account the tractor power availability and the traction

Table 3. The results of field tests carried out for evaluation of the effect of forward speed on traction parameters

Site	Soil condition	Tractor-offset disc harrow (angle between disc gangs, degree)	v_r (km h^{-1})		T (kN)		$\mathfrak{I}$ (kN m^{-1})	Re (N cm^{-2})
			Average	SD	Average*	SD	Average	Average
1-a	Primary tillage	Massey-Ferguson 3060	3.62	0.24	15.89[a]	1.55	7.68	4.26
		HPR 20-24	5.37	0.32	16.80[b]	1.80	8.12	4.51
		(46)	6.84	0.35	16.74[b]	1.41	8.08	4.49
1-b	Primary tillage	Massey-Ferguson 3060	3.64	0.26	13.57[a]	1.38	6.46	3.59
		HPR 20-24	5.65	0.37	13.93[b]	1.32	6.63	3.69
		(37)	7.40	0.38	13.92[b]	1.49	6.63	3.68
2-a	Primary tillage	Massey-Ferguson 3060	5.12	0.33	14.05[a]	1.37	6.47	3.92
		HPR 20-24	6.12	0.38	14.15[b]	1.20	6.52	3.95
		(46)	7.91	0.32	14.49[c]	1.08	6.68	4.05
2-b	Primary tillage	Massey-Ferguson 3060	5.33	0.40	12.46[a]	1.38	5.93	3.60
		HPR 20-24	6.17	0.38	12.53[b]	1.25	5.97	3.62
		(37)	8.91	0.42	13.34[c]	1.17	6.35	3.85
3	Primary tillage	Massey-Ferguson 3060	4.80	0.32	14.03[a]	1.26	5.59	3.49
		HPR 24-24	6.55	0.36	14.70[b]	1.26	5.86	3.66
		(37)	7.68	0.35	14.93[c]	1.76	5.95	3.72
4	Primary tillage	Massey-Ferguson 3060	4.85	0.37	15.25[a]	1.50	5.93	4.09
		HPR 24-24	6.49	0.47	15.68[b]	1.64	6.10	4.21
		(37)	7.69	0.44	16.11[c]	1.77	6.27	4.32
5	Primary tillage	Massey-Ferguson 3650	4.80	0.30	25.52[a]	1.60	8.83	4.91
		GSM 24-28	6.40	0.35	26.83[b]	1.89	9.28	5.16
		(44)	6.70	0.36	27.42[c]	1.69	9.50	5.28
6-a	Secondary tillage	Massey-Ferguson 6180	5.70	0.39	20.32[a]	1.92	7.67	5.11
		FI/RTF 24-26	6.60	0.32	21.29[b]	1.95	8.03	5.36
		(52)	8.50	0.36	23.02[c]	1.87	8.68	5.79
6-b	Secondary tillage	Massey-Ferguson 6180	5.70	0.41	18.05[a]	1.95	6.49	4.33
		FI/RTF 24-26	6.50	0.37	18.65[b]	1.61	6.71	4.47
		(46)	8.60	0.35	21.04[c]	1.54	7.57	5.05
6-c	Secondary tillage	Massey-Ferguson 3060	4.33	0.26	13.36[a]	1.53	6.52	4.07
		HPR 20-24	5.79	0.35	13.29[a]	1.67	6.48	4.05
		(46)	7.20	0.35	14.22[c]	1.67	6.94	4.33
6-d	Secondary tillage	Massey-Ferguson 3060	4.40	0.24	11.54[a]	1.46	5.42	3.39
		HPR 20-24	5.87	0.30	11.79[b]	1.37	5.53	3.46
		(37)	6.91	0.27	11.82[b]	1.63	5.55	3.47
7	Secondary tillage	Massey-Ferguson 3680	4.15	0.29	23.32[a]	1.88	6.12	3.22
		GLHR 36-26	5.80	0.34	23.96[b]	1.83	6.29	3.31
		(42)	8.85	0.37	25.47[c]	1.83	6.68	3.52

v_r: forward speed, km h^{-1}. T: draught, kN. $\mathfrak{I}$: draught unit^{-1} of implement width, kN m^{-1}. Re: draught unit^{-1} cross-sectional area of the tilled zone, N cm^{-2}. SD: standard deviation. * Average values followed by a different letter are significantly different.

requirements of the implement, without reducing the safety and comfort of the operator, the quality of the work performed and the engine speed under load.

At each test site to match the field trails to real farming conditions, the opinion of the farmer, regarding the soil conditions, for harrowing, was taken into account.

Each area was subdivided into 12 plots of 50 m length and 4 m width, where flags with three different colours (levels of forward speed) had been placed at random, to indicate the start and end of each treatment.

In each area the operator carried at the four replications each speed level and only then did he proceeded to the next speed.

Depth was measured with reference to the undisturbed soil surface adjacent to the tilled area. The average operating depth of the mobilised soil layer was taken from at least 20 measurements in the 50 m run and each value was the average of three measurements taken across the width of each run.

The average working width was obtained from 12 direct measurements across each 50 m of the harrowed area.

The statistical processing of the results was analysis of variance of the relevant parameters, according to the experimental values established in the tests and using the statistical programme «MSTAT-C». Averages were separated using the Duncan multiple separation test.

Results and Discussion

The results in Table 3 correspond to the average of the measured parameters in the set of the repetitions carried out for each treatment.

Table 3 shows the site and soil condition (primary or secondary soil tillage), the tractor model (maximum power), the characteristics of the trailed disc harrow used at each site, including the gang angle (α, in degrees) and the parameters forward speed (v_r), draught (T), draught unit^{-1} of implement width ($\Im$) and draught unit^{-1} cross-sectional area of the tilled zone (Re).

The results (Table 3) show a systematic trend for a slight increasing of draught parameters as an effect of working speed. The analysis of variance showed differences in the draught (and specific draught) which were highly significant ($p < 0.01$) in 9 out of 12 of the tests performed and significant differences ($p < 0.05$) in 3 out of the 12 tests (see different letters «a, b and c» in the Table 3, column «Average Draught»).

This trend accords with the predictions of Ramp and Siemens (1990), Harrigan and Rotz (1994, 1995), and Siemens (1996) (Equation [1]).

$$\mathrm{Re} = Fi.[a + b(v_r) + c(v_r)^2] \qquad [1]$$

where Re (draught unit^{-1} cross-sectional area of the tilled zone, N cm^{-2}), F_i (coefficients of the soil texture: 1 to fine textured soil, 0.88 for medium textured soil and 0.78 for coarse textured soil), *a, b, c* (regression coefficients) and v_r (forward speed, km h^{-1}).

Table 4 presents the values of the coefficients *a, b* and *c,* considered by these authors for trailed disc harrows, depending on soil texture and soil condition. In the proposed model, the authors categorized soil as fine, medium, and coarse. These categories were described as corresponding to clay, loamy, and sandy soils, respectively. Therefore for disc harrows, the relation between draught and speed is considered to be linear, with the form of Equation [2].

$$\mathrm{Re} = Fi.[a + b(v_r)] \qquad [2]$$

These equations allow the estimation of an average increase in draught unit^{-1} cross-sectional area of the tilled zone of 7.7% in primary soil tillage and of 2.3% in secondary soil tillage, with a typical speed interval between 6 and 8 km h^{-1}. On average, in the set of seven tests carried out on primary soil tillage, in medium textured soils, the increased verified draught unit^{-1} cross-sectional area of the tilled zone in the same speed interval was 3.9%, while in the five tests on secondary soil tillage, in fine textured soil, the increase in this parameter was 6.6%.

Thus, it was confirmed, the little effect of speed on the draught unit^{-1} cross-sectional area of the tilled zone. The same happens in relation to the draught and in relation to the draught unit^{-1} of implement width (Ta-

Table 4. Regression coefficients of equation [1] proposed by Ramp and Siemens (1990), Harrigan and Rotz (1994, 1995) and Siemens (1996) for application to offset disc harrows

Soil condition	Soil texture	Regression coefficients		
		a	b	c
Primary tillage	Fine	3.64	0.19	0
	Medium	3.20	0.16	0
	Coarse	2.84	0.14	0
Secondary tillage	Fine	2.54	0.13	0
	Medium	2.24	0.12	0
	Coarse	1.99	0.09	0

Table 5. Regression coefficients of Equation [2] to estimate the linear effect of working speed on draught unit^{-1} cross-section area of the tilled zone

Site	Soil condition	Disc harrow (α, degree)	Regression coefficients		R^2
			a	b	
1-a	Primary tillage	Herculano HPR 20-24 (46)	4.0394	0.0729	0.74
1-b	Primary tillage	Herculano HPR 20-24 (37)	3.5106	0.0257	0.75
2-a	Primary tillage	Herculano HPR 20-24 (46)	3.6859	0.0452	1.00
2-b	Primary tillage	Herculano HPR 20-24 (37)	3.1788	0.0747	0.98
3	Primary tillage	Herculano HPR 24-24 (37)	3.1135	0.0805	0.98
4	Primary tillage	Herculano HPR 24-24 (37)	3.6949	0.0809	0.99
5	Primary tillage	Galucho GSM 24-28 (44)	4.0200	0.1834	0.97
6-a	Secondary tillage	Fialho FI/RTF 24-26 (52)	3.7480	0.2408	1.00
6-b	Secondary tillage	Fialho FI/RTF 24-26 (46)	2.8668	0.2524	0.98
6-c	Secondary tillage	Herculano HPR 20-24 (46)	3.6631	0.0900	0.96
6-d	Secondary tillage	Herculano HPR 20-24 (37)	3.2515	0.0329	0.95
7	Secondary tillage	Galucho GLHR 36-26 (42)	3.1134	0.0674	1.00

ble 3). The coefficients *a* and *b* of the linear Equation [2] are given in Table 5 for each condition in the field trails.

In terms of general inference of the draught of trailed disc harrows, Figures 1 and 2 show the results obtained from the model of Ramp and Siemens (1990), Harrigan and Rotz (1994, 1995) and Siemens (1996), respectively for primary tillage of medium textured soils («Linear Model Har & Rotz-Medium») and for secondary tillage of fine textured soils («Linear Model Har & Rotz-Fine»). An approach between estimated values and measured values in primary tillage was verified, suggesting the possible use of this model for the provision of draught in offset trailed disc harrows.

In secondary soil tillage, the model gives a lower estimate than the measured values. Two aspects can possibly explain this. Firstly, the results were obtained with two angles between the gangs of the same harrow, a feature which is not mentioned in the forecasting model which had considerable influence on the required draught for trailed disc harrows (Serrano *et al.*, 2003). Secondly, Harrigan and Rotz (1994, 1995) and Siemens (1996), had reference values of 0.58 up to 0.93. Reid (1978) and Reid *et al.* (1983) with regard to soil texture,

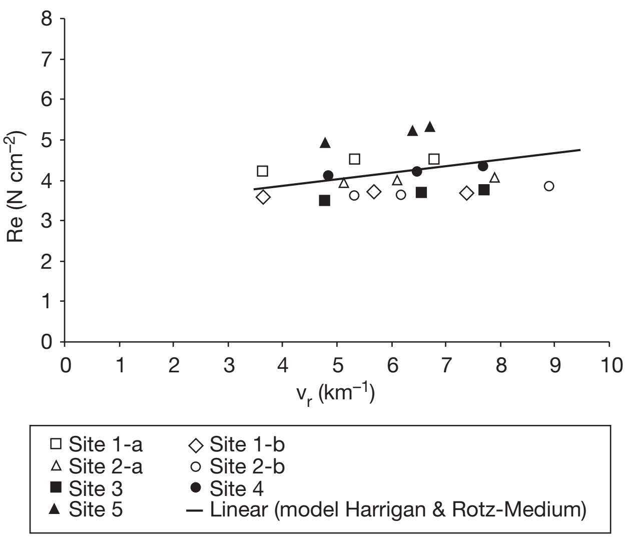

Figure 1. The results of draught unit^{-1} cross-section area of the tilled zone as a function of forward speed in the model of Harrigan and Rotz (1994, 1995), for primary tillage of medium textured soil.

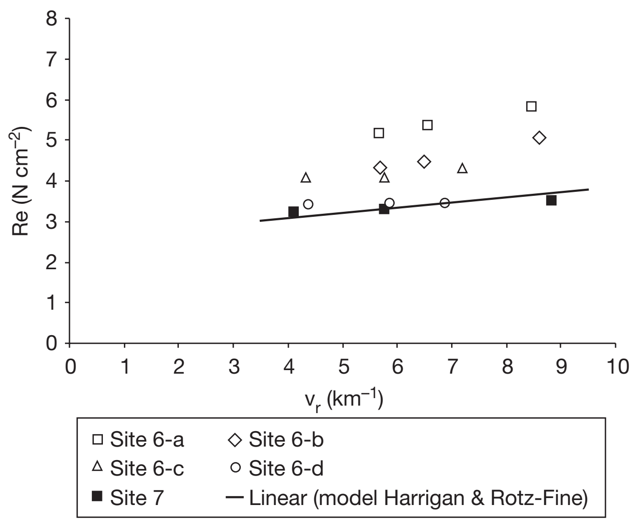

Figure 2. The results of draught unit^{-1} cross-section area of the tilled zone as a function of forward speed in the model of Harrigan and Rotz (1994, 1995), for primary tillage of a fine textured soil.

indicated an average factor of 0.70 affected the draught unit^{-1} cross-section area of the tilled zone by trailed disc harrows, in secondary tillage, relative to primary tillage. The same authors report that the effort required to disc a soil is normally greater in primary than in secondary tillage. They indicate that sometimes, draught is perceived to be greater in secondary tillage due to increased operating depth and reduced traction efficiency in tilled soil. This question justifies the conduct of more conclusive field trails.

Conclusions

The field trails, carried out under real conditions of work, demonstrated that the draught required for trailed disc harrows tends to increase slightly with forward speed. The relationship is linear and gives a general model of the draught required for primary tillage, as presented by Harrigan and Rotz (1994, 1995), Ramp and Siemens (1990) and Siemens (1996), for updating the ASAE *Standards*. In secondary soil tillage, the under estimation of the model justifies more study in this area with the aim of validating the general predictive model.

Acknowledgements

The authors acknowledge funding provided by the Programme Supporting the Modernising of Portuguese Agriculture and Forestry-PAMAF-8.140.

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