The spading machine as an alternative to the plough for the primary tillage

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Abstract

A comparison between a traditional ploughing and a spading (performed at different travelling and rotor speeds) was carried out in a paddy field, for evaluating both technical and agronomic parameters (working time, power required, fuel consumption, pulling force, efficiency of crop residues incorporation, *etc.*). The ploughing showed an effective tillage capacity 51% higher than the faster spading, and a reduction ranging between 20.8 and 44.1% of fuel consumption per surface unit. On the contrary, the spading machine requested no or minimum pulling force, making possible its use even in critical conditions, as for example on wet soil. On the other hand, the spading machine shows clear advantages under the agronomic point of view: in fact it does not create the typical compact layer at the bottom of the working depth, which reduces the root penetration and does not allow the capillary circulation of the solution into the soil. Indeed, in the paddy field the creation of a compact layer is able to reduce the water consumption, so it is not considered a problem to be solved. In any case, the spading machine better managed the crop residues, because they were mixed along the completely tilled layer.

Introduction

The primary tillage of the soil is the operation that deals with the breaking of the previously cultivated soil, with a mixing up (or a complete inversion) of the top layer. To obtain this goal, in the past the plough was quite frequently been used. In the last years, for reducing the economic and environmental impact of the tillage as well as to maximise the crop production, some alternative solutions raised a significant success, such as zero or minimum tillage. This involved the use of alternative machinery instead of the plough (Hoffman, 1993; Borin *et al.*, 1997).

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The soil-tool interactions and the field performance of various implements have been extensively studied considering the initial soil condition, tool shape, tool speed and the movement of drawn and power take-off (PTO) driven implements (Perdok and Kouwenhoven, 1994).

In Italy, and more in general in the Mediterranean area, the spading machine has had a discrete success. If compared to the ploughing, the main advantages of the spading machine use are the absence of a compact layer at the bottom of the tilled soil and the reduced (or sometime even zero) drawbar pull required (Gasparetto, 1966a).

The spading machine is an implement coupled to the 3-point hitch of the hydraulic lift and operated through the tractor PTO. A strong frame is supporting the spades, the working tools having a trapezoidal shape, which are located on the end of the connecting rods being part of articulated quadrilateral mechanisms. They are taking the movement from a central gearbox through a rotor. Notwithstanding the development in the past of rotating machines (Pellizzi, 1965; Gasparetto, 1970), the models currently on the market are all based on the connecting rod-crank mechanisms, also called articulated quadrilateral mechanism. This system is based on a bridge (the fixed part faced to the tractor rear side), a rod opposed to the bridge that bears the spade, a crank and a rocking arm (Figure 1). The machine operates the cut of a slice of soil, which is torn off and launched behind the machine, so that it is crumbled.

Gasparetto in 1966 studied accurately under the kinematic point of view various types of spading machines, both as for the movement paths and for the speed and acceleration produced. The illustrated type of quadrilateral mechanism was judged as being the most efficient.

In the 80s of the last century, the spading machine raised interest, mainly in Italy. In fact, the most important manufacturers are Italian (Baraldi and Pezzi, 1987). Moreover, many papers concerning the spading machine were written more than 40 years ago by Italian authors (Gasparetto, 1966b, 1968). Unfortunately, the results of those tests cannot be referred nowadays, because at that time ploughs were characterised by a limited working width, a factor reducing their performance. More recent analysis, carried out at the end of '90 of the last century (Peruzzi *et al.*, 1997; Pezzi *et al.*, 1997) regarded only the performance analysis of the spading machine, without comparing it directly with other implements.

The aim of this research was to compare a traditional ploughing and a spading, considering both technical and agronomic parameters (working time, power required, fuel consumption, pulling force, efficiency of crop residues incorporation, *etc.*).

Materials and methods

The tests were carried out in March 2013, in a paddy field located in Novara province, inside of a large rice cultivated area in Northern Italy. The soil of the test site was a loamy soil (USDA, 2015) (25% clay, 33% silt, 42% sand). The same crop was constantly cultivated for a very long time (approx. 50 years) in the investigated field. In this period, the only soil tillage combination executed was the ploughing followed by a rotary harrowing.

The investigated area was previously characterised through the ascertaining of the soil moisture content, the covering index (the ratio between the area covered by crop residues and the entire soil surface, detected via a software of high resolution image analysis) and the soil penetration resistance. The soil moisture content was evaluated adopting the wet basis method, *i.e.,* the gravimetric difference between the wet and the dry mass of a soil sample after drying at 105°C, compared with the wet mass. The covering index of the residues was calculated starting from high-resolution images, with the Image-Pro Premier software (Media Cybernetics, Inc., Rockville, MD, USA). Using the same software, the efficiency of the incorporation of crop residues into the tilled layer was estimated, comparing the covered surface of the soil before and after the tillage.

The soil penetration resistance was measured with a cone penetrometer, equipped with a 30° inclination cone of 1 cm^2 total base area, as defined in ASAE S313.3 (ASAE, 1999b) and ASAE EP542 (ASAE, 1999a). The surface of investigated field was 1.83 ha; 275 sample measurements were executed, distributed randomly over the entire area.

The two tested implements was a spading machine, make Selvatici model 150.150 P2510, and a plough, make Vogel&Noot model Permanit M850. The main technical characteristics of the two implements compared are shown in Table 1.

The two implements were both coupled to a 4WD tractor Same Tiger Six 105, with an engine power of 77.2 kW and total mass of 4570 kg (included 250 kg of front ballasting), distributed for 42% (1920 kg) on the front axle and for 58% (2650 kg) on the rear axle (Figure 2).

The gross drawbar pull was measured using a load cell, make DS Europe model LC having a full-scale of 50 kN. The cell was placed on a drawbar pull beam (Figure 3) located between the tractor coupled alternatively with the two implements and another 4WD tractor used to pull, a Kubota M128X, of 94.1 kW maximum power and a total mass of 5320 kg (included 600 kg of front ballasting) (Figure 4). To obtain the net drawbar pull, the rolling resistance (measured by towing the tractor Same Tiger Six 105 without load, with the plough and the spading machine not working) was measured and deducted from the gross drawbar pull.

The fuel consumption was measured thanks to a differential flow meter, make Fuel View model DFM-50/100. The gross engine power absorbed for the two tillage operations was calculated indirectly. The basic data were the measured volumetric hourly fuel consumption (l h^{-1}), the measured density of the fuel (835 kg m^{-3}) and the engine speed maintained for both operations (204.4 rad s^{-1}), setting the engine at full load. The specific fuel consumption value of 280 g kWh^{-1} was then considered, drawn from the corresponding full load curve of the PTO test published in the Organisation for Economic Co-operation and Development (OECD) official report of the tractor Same Tiger Six 105 (OECD, 1981, unpublished data).

Starting from the data recorded in the field tests and those belonging from the OECD report, the values of wheel-slip, effective drawbar pull or effective power, specific resistance or specific power, etc. were cal-

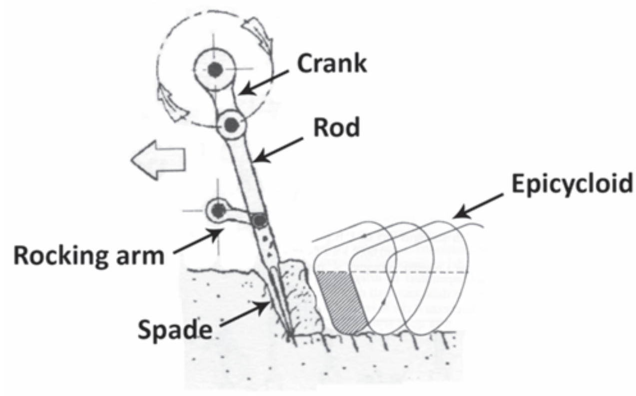

Figure 1. Nomenclature of the main parts of the spading machine (modified from Biondi, 1999; Bodria *et al.*, 2006).

Figure 2. The 4WD tractor Same Tiger Six 105 working with the plough (left) and the spading machine (right).

Table 1. Main technical characteristics of the reference and test implements compared.

Characteristic	Plough (reference)	Spading machine (test)
Make	Vogel&Noot	Selvatici
Model	Permanit M850	150.150-P2510
Type	Reversible 4-furrow	10 spades
Theoretical working width, m	1.55	2.45
Theoretical working depth, cm	24	24
Mass, kg	1070	1320
Tractor min-max power requirement (manufacturer data), kW	50-88	51-110

Table 2. Investigated working conditions of the spading machine.

Test condition	PTO speed, min^{-1}	Gear, no. - rotating speed, rad s^{-1}	Travelling speed, m s^{-1}	Cutting interval, m
A	1000	3-21.5	0.42	0.123
B	1000	1-14.7	0.78	0.334
C	1000	2-17.1	0.63	0.232

PTO, power take-off.

culated. The working quality was evaluated analysing the crop residues incorporation efficiency, being the ratio between the covering index of the soil before and after the tillage. Both implements were settled to work at a theoretical depth of 24 cm, referring to the untilled soil. The effective working depth was checked by measuring this parameter into the field test in randomised locations. The ploughing was carried out at a theoretical travelling speed of 2.33 m s^{-1} (*i.e.,* the tangential velocity of the driving wheels). The spading machine was tested by setting 3 different rotor and travelling speed values, aimed to find the performance limits of the machine, varying both the travelling and the rotor speeds, to obtain different cutting intervals (Table 2). For each test condition, both the implements worked at least 0.5 h; the pulling force measurements were repeated 3 times, on a path of at least 100 m long.

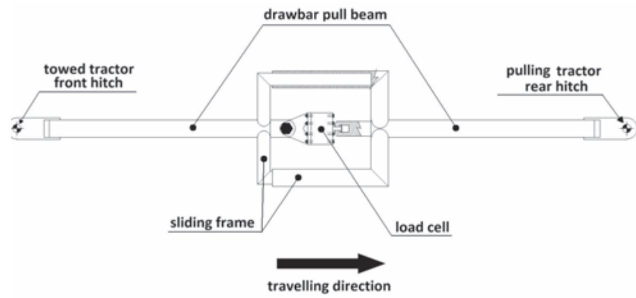

Figure 3. Sketch of the drawbar pull beam; the load cell is located in the centre of the sliding frame.

Results and discussion

Soil characteristics

The soil moisture content of the tilled layer was 22% in the top part and 26% at a theoretical depth of 24 cm. The values are higher than those considered suitable for the soil tillage, but it is well known that the paddy fields are characterised by a remarkable water retention (Bouman *et al*., 2007). The resistance to penetration (Figure 5) highlights a very compact layer at a depth ranging from 30 to 40 cm, due to the previous repeated passages of the plough. For many crops this is a problem, but in the paddy field this is considered a favourable condition, because it reduces the water consumption necessary to maintain the submersion of the surface. The real working depth, compared to the untilled soil and obtained through several measurement repetitions was 24±2 cm, for both implements.

Performance parameters

Notwithstanding the lower effective working width (–34%), for the plough a higher tillage capacity (ranging from 51 to 141%) was recorded, due to its travelling speed, which is about 3 times than that of the spading machine (Table 3). On the other hand, with the plough the wheel-slip was quite higher than that recorded with the spading machine, due to the remarkable draft pulling required. In another survey (Peruzzi *et al.*, 1997) conducted on a quite similar spading machine (2.5 m working width, 10 spades), the Authors found the fairly same effective working capacity (0.31-0.38 ha h^{-1}).

Considering the environmental and economic sustainability of the soil tillage, the fuel consumption is one of the parameters having a high impact. The hourly consumption of the plough is 28% higher than that recorded as an average for the spading machine. On the contrary, considering the consumption per surface unit, the plough highlighted a value remarkably lower than those of the spading machine, in all working conditions investigated.

As expected, the plough needed a significant pulling force. On the contrary, the spading needs practically only power through the PTO; in some cases (*i.e.* high travelling speed, but low rotation speed of the tools) the pulling is negative. In other words, in this condition the spading machine is not pulled, but it is slightly pushing the tractor.

In ploughing, the 87% of the maximum engine power was engaged, while for the spading operation an amount ranging from 64 to 72% was necessary. A higher power value was required in the intermediate working condition, with medium travelling and rotor speed values. This is justified both by the relatively small dimension of the clods created and by the fairly good travelling speed. For the ploughing of the medium textured soils, like that of the tests, the specific resistance value is normally ranging from 500 to 800 N m^{-1}cm^{-1} (Caprara, 2010). *Vice versa*, always for the medium textured soil, the absorbed power through the PTO is usually

Figure 4. The combinations implement-tractors arranged for the tests: the plough (top) and the spading machine (bottom).

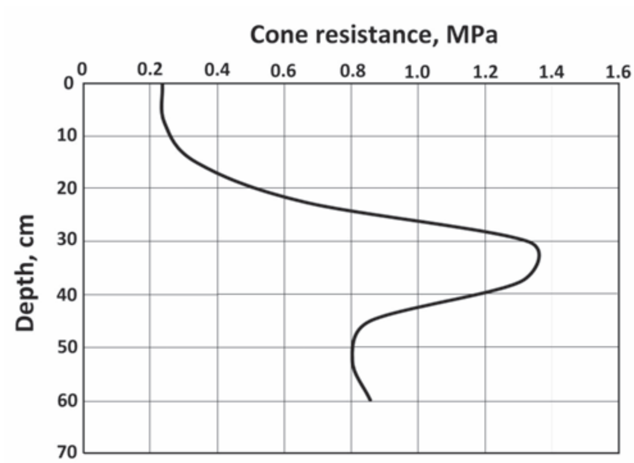

Figure 5. Penetration resistance of the tested soil.

considered, ranging between 500 to 800 W m^{-1} cm^{-1} (Caprara, 2010). The values obtained in the surveyed spading were subjected to statistical analysis by Student's *t* test, to determine the significance of differences. In the investigated range, the values for the conditions A and B differ significantly ($P<0.01$); the intermediate condition (C) does not differ significantly for both conditions (Figure 6). Moreover, the specific power shows a strong correlation with the effective travelling speed (R^2 0.97).

To obtain a seedbed as uniform as possible in terms of clods dimensions, a rotary harrow was then used, performing a single passage at different travelling speeds. The results obtained are shown in Table 4. The effective speed ranged from 0.83 to 1.67 m s^{-1}, and the effective tillage capacity varied from 0.88 to 1.76 ha h^{-1}. The fuel consumption per surface unit of the rotary harrow is higher after plough, and lower in condition A of spading. However, the total fuel consumption per surface unit was higher in all-spading conditions, increasing from 10% to 35% in comparison with the ploughing.

Agronomic parameters

As expected, with the ploughing the incorporation efficiency of the residues was excellent (97.6%), while with the spading machine it ranged from 82.3% to 84.1% (Figure 7), showing a slight variation in respect to the working settings (Table 5). Indeed, the ploughing does not mix the residues into the completely tilled layer, but it tends to concentrate them at the bottom of the furrow. On the contrary, with the

Table 3. Results of the tests.

	Plough		Spading machine					
			A		B		C	
	Means	SD	Means	SD	Means	SD	Means	SD
Theoretical travelling speed, m s^{-1}	2.33	-	0.42	-	0.78	-	0.63	-
Effective travelling speed, m s^{-1}	1.77	0.04	0.40	0.02	0.73	0.03	0.58	0.06
Wheel-slip, %	24.03	0.02	4.79	0.06	6.42	0.04	7.91	0.08
Effective working width, m	1.55	0.04	2.34	0.07	2.34	0.07	2.34	0.07
Effective tillage capacity, ha h^{-1}	0.77	0.01	0.32	0.01	0.51	0.01	0.45	0.01
Hourly fuel consumption, kg h^{-1}	18.70	0.36	13.82	0.25	15.59	0.49	14.53	0.42
Specific fuel consumption, g kWh^{-1}	280							
Consumption per surface unit, kg ha^{-1}	24.3	0.3	43.5	0.1	30.7	0.8	32.3	0.8
Gross engine power, kW	66.8	1.3	49.3	0.9	55.7	1.8	51.9	1.5
Gross drawbar pull, kN	26.7	0.7	4.3	0.2	2.8	0.6	2.9	0.3
Rolling resistance, kN	4.1	0.2	4.1	0.2	4.1	0.2	4.1	0.2
Net drawbar pull, kN	22.6	0.7	0.2	0.2	–1.3	0.6	–1.2	0.3
Effective power absorbed, kW	-	-	33.5	0.6	37.9	1.2	35.3	1.0
Width-depth of tilled soil, m	1.55-0.24		2.34-0.24					
Specific resistance, N $m^{-1}cm^{-1}$	608	20	-	-	-	-	-	-
Specific power, W $m^{-1}cm^{-1}$	-	-	597	11	674	21	628	18

SD, standard deviation.

Table 4. Tillage capacity and fuel consumption for the seedbed preparation.

	Plough		Spading machine					
			A		B		C	
	Means	SD	Means	SD	Means	SD	Means	SD
Rotary harrow effective working width, m	3.45	0.04	3.45	0.04	3.45	0.04	3.45	0.04
Rotary harrow effective tillage capacity, ha h^{-1}	0.88	0.01	1.76	0.03	0.88	0.01	1.47	0.05
Rotary harrow hourly consumption, kg h^{-1}	13.5	0.3	17.9	0.7	13.7	0.6	16.6	0.3
Rotary harrow consumption per surface unit, kg ha^{-1}	15.3	0.3	10.2	0.2	15.5	0.6	11.3	0.3
Primary tillage consumption per surface unit, kg ha^{-1}	24.3	0.3	43.5	0.1	30.7	0.8	32.3	0.8
Total consumption per surface unit, kg ha^{-1}	39.6	0.6	53.7	0.2	46.2	1.3	43.6	0.5

SD, standard deviation.

Table 5. Crop residues incorporation in ploughing and spading.

	Plough		Spading machine					
			A		B		C	
	Means	SD	Means	SD	Means	SD	Means	SD
Initial covering	0.931	0.007	0.931	0.007	0.931	0.007	0.931	0.007
Final covering	0.022	0.003	0.153	0.004	0.165	0.006	0.148	0.007
Efficiency, %	97.6	0.3	83.6	0.4	82.3	0.6	84.1	0.7

SD, standard deviation.

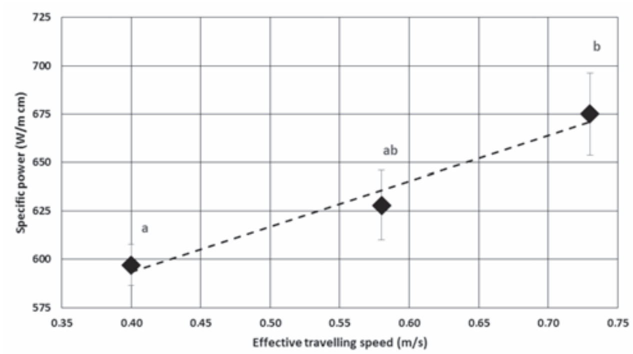

Figure 6. Correlation between specific power take-off and effective travelling speed.

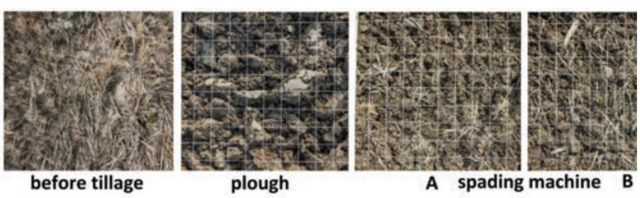

Figure 7. View of the soil surface for the incorporation of the crop residues in the soil tilled with the plough and the spading machine.

spading machine the residues are better distributed into the soil, so that their decomposition into humus is favoured.

Conclusions

Apart the technical and agronomic evaluation, the comparison between the ploughing and the spading performance could be improved considering also the working capacity for the preparation of a seedbed of equivalent characteristic (*i.e.* clod dimension). Under this point of view, the ploughing and harrowing combination evidenced 2.44 h ha^{-1}, while the 3 different combinations of spading and harrowing ranged from 2.90 (condition C) to 3.69 h ha^{-1} (condition A). In the C condition (medium rotor and travelling speed) the working capacity of the spading and harrowing combination is only slightly higher (19%) than the traditional ploughing harrowing combination. Apart the increased cost of the fuel consumption, this certainly leads to a higher manpower cost. On the other hand, for the real convenience of the two solutions also the agronomic advantaged should be evaluated and taken into account. Unfortunately, the advantages of the spading, *i.e.* the better residues incorporation and the absence of the soil compacted layer, cannot be easily evaluated, because in this case the crop yield and quality should be checked for a significant time period.

In any case, it is important to remember that with suitable soil texture conditions a single passage of the spading machine could be sufficient to create optimal conditions for the seeding, while after the ploughing is always necessary one or more subsequent harrowing. This could be a profitable opportunity in horticulture and floriculture, where many cultivation cycles per year are normally carried out, and the timeliness in soil tillage becomes an important factor for optimising the growing.

References

ASAE. 1999a. ASAE Standards 4E. EP542: procedures for obtaining and reporting data with the soil cone penetrometer. St. Joseph, MI, USA.

ASAE. 1999b. ASAE Standards 4E. S313.2: soil cone penetrometer. St. Joseph, MI, USA.

Baraldi G., Pezzi F. 1987. Caratteristiche tecniche e prestazioni delle vangatrici. Inf. Agr. 40:45-51.

Biondi P. 1999. Meccanica agraria. UTET, Torino, Italy.

Bodria L., Pellizzi G., Piccarolo P. 2006. Meccanica agraria, vol. 1. Edagricole, Bologna, Italy.

Borin M., Menini C., Sartori L. 1997. Effects of tillage systems on energy and carbone balance in north-eastern Italy. Soil Till. Res. 40:209-26.

Boumand B.A.M., Humpreys D., Tuong T.P., Barker R. 2007. Rice and water. Adv. Agron. 92:187-237.

Caprara C. 2010. La filiera agro-energetica da colture dedicate: un modello GIS per la pianificazione agroindustriale. In: Biomasse: prospettive di uso energetico in Emilia-Romagna e sistemi di calcolo e monitoraggio su GIS. Università di Bologna, Italy. Available from: http://energia.regione.emilia-romagna.it/entra-inregione/documenti-e-pubblicazioni/eventi/2010/biomasse-prospettive-uso-energetico-in-emilia-romagna/CAPRARA_La_filiera_agro_energetica_da_colture_dedicate_un_modello_GIS_per_la_pianificazione_agroindustriale.pdf/at_download/file/CAPRARA_La_filiera_agro_energetica_da_colture_dedicate_un_modello_GIS_per_la_pianificazione_agroindustriale.pdf

Gasparetto E. 1966a. Cinematica e dinamica di vangatrici a quadrilatero articolato. Quaderni I.S.M.A. 17:3-33.

Gasparetto E. 1966b. Nuove prove sperimentali di macchine vangatrici. Il Riso 3:193-209.

Gasparetto E. 1968. Prove comparative di differenti attrezzi per la lavorazione del terreno in risaia. Inf. Agr. 12:53-62.

Gasparetto E. 1970. Analisi del comportamento cinematico e dinamico di una vangatrice a elementi rotanti. Il Riso 2:143-163.

Hoffman M. 1993. The spading machine. A substitute for the plough in ecological farming? Landtechnik. 48:29-31.

Pellizzi G. 1965. Primi accertamenti sperimentali su nuove vangatrici. Il Riso 3:209-222.

Perdok U.D., Kouwenhoven J.K. 1994. Soil-tool interactions and field performance of implements. Soil Till. Res. 30:283-326.

Peruzzi A., Raffaelli M., Ginanni M., Di Ciolo S. 1997. Analisi delle prestazioni di una vangatrice. Macchine & Motori Agricoli. 6:13-20.

Pezzi F., Bovolenta S., Venturi I. 1997. La lavorazione del terreno con la bivanga. Macchine & Motori Agricoli. 6:69-73.

USDA. 2015. Soil Survey Staff, Natural Resources Conservation Service. Soil Series Classification Database. Available from: http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/class/?cid=nrcs142p2_053583 ortal/nrcs/detail/soils/survey/class/?cid=nrcs142p2_053583