COMPARISON OF ENERGY REQUIREMENTS OF TRADITIONAL AND CONSERVATIVE SOIL TILLAGE FOR MAIZE CULTIVATION IN CENTRAL ITALY

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ABSTRACT Traditional soil tillage for summer maize cultivation in Central Italy is based on medium depth ploughing followed by refinement of the surface for preparing the seedbed. Such a technique can involve excessive energy costs, loss of nutrients, decrease of natural soil fertility and, in some cases, increase of erosion phenomena caused by wind and water. These negative effects can be reduced by introducing conservative soil tillage techniques, such as tilling without inversion of layers and minimum tillage, which aim at maintaining a permanent soil cover and at reducing the number and the depth of the interventions. The CPMA of CRA-ING is specialized in testing of machines for soil tillage and sowing. During its activity, the tests of more than 50 machines of various types have been carried out on soil characterized by homogeneous clay-loam texture, widespread in Central Italy, providing a complete picture of their dynamic-energetic performances and of the work quality. Through the combination of data of the properly selected machines, according to the criteria of homogeneity, it has been possible to compose 5 tillage methods (2 traditional and 3 conservative) aimed at maize sowing, both in spring and summer in succession to wheat. Through the analysis of the parameters measured in the tests, for each method an estimate of the quality of work and the energy requirements has been provided. The results show increasing energy savings progressively moving from traditional to more conservative tillage methods, up to a maximum of 70%, without significant quality decrease of seedbed.

Keywords: Testing, Performance, Energy requirement, Primary and secondary soil tillage.

INTRODUCTION Traditional soil tillage based on deep ploughing, on burning or mulching of residues from previous crops may create a number of side effects, as pointed out by numerous experiments in the field of agricultural mechanization, such as: excessive energy requirements and costs; the worsening, in some cases, of soil structure;

loss of nutrients in the deeper layers and of the organic matter in the higher layers; increasing erosion phenomena caused by wind or by surface water. These effects can be avoided, in many cases, by replacing conventional tillage with suitable soil conservation tillage techniques, that allow to reduce the number of operations and the working depth, by using multi-function machines with wide work front. These techniques, through crop rotation and maintenance of permanent soil cover of at least 30% of the surface, aim at reducing the erosion and compaction of soil surface and at preserving its natural fertility, ensuring at the same time, a satisfactory level of production and reduced energy costs. Excluding the inversion of layers, conservative techniques are based on a wide range of possible interventions, such as soil unpacking by means of subsoilers and combined machines; minimum tillage (disc harrows, cultivators, equipment combined); the chopping of plant residues; sod seeding (hard from seed); direct seeding after light surface intervention (sowing machine combined with disc harrow, toothed harrow, rotary harrow, etc.).

The Agricultural Machinery Test Center (CPMA) of CRA-ING is specialized in the relief of operational (energy requirements) and qualitative (quality of work) performances of the operative machines used in conventional and conservative soil tillage techniques (Colorio et al., 2009; Fanigliulo and Pochi, 2008; Fanigliulo et al., 2009; Peruzzi et al., 1999; Pochi and Fanigliulo, 2010) and precision drills (Fanigliulo et al., 2008). In its activity, 50 machines were tested, after which it was possible to obtain for each machine a full picture of its performance considering both dynamic-energetic and quality-of-work aspects. The availability of this information helped to combine data from different machines, selected according to criteria of homogeneity (front and depth of work, power required, etc.), in order to compose 5 methods (2 traditional and 3 conservative), aimed at maize seeding.

The aim of this work is to provide, for the 5 working methods, an estimate of the requirements of work and energy, through the analysis of working time, fuel consumption, power requirements and total energy per surface unit (Pochi et al., 1996; Perfect et al., 1997). The tests were conducted from 2004 to today, at the CRA-ING of Monterotondo (Rome, Italy), on plots with soil characterized by a homogeneous clay-loam texture. For the determination of the main operative parameters of each coupling tractor-operative machine, tests were performed in accordance with the protocol for the relief of functional characteristics of soil tillage machines, proposed by E.NA.MA, National Body for Agricultural Mechanization (ENAMA, 2003).

MATHERIAL AND METHODS The main technical data of the tested machines are reported in table 1.

Table 1. Main technical data of the tested machines.

Parameters	Three furrow, reversible plough	Rotary harrow	Precision drill	Flail chopper	Disks harrow	Combined cultivator
Working width (m)	1.97	4.02	6.00	6.18	4.32	3.96
Working depth (m)	0.45	0.19	0.04	-	0.12	0.08
Type of working tools	skim coulter, knife ploughshare, mouldboard	vertical blades	double disk, soil scraper, coulter	flail rotor, roller	plain and notched disks	teeth, disks, rollers
Tools number	3x2	32	8	64	36	9+8+2
Distance between tools (m)	1.27	0.25	0.75	0.1	240	440
Total mass (kg)	2620	1995	1600	2250	4510	1920

The machines were moved by a 4WD tractor with nominal power of 205 kW and total mass of 107.873 N. The p.t.o. speed was 1000 min^{-1} corresponding to an engine speed of 1974 min^{-1}. Before the sowing tests, the engine performances were verified at the dynamometric brake that provided the updated characteristic curves of the engine. The dynamometric brake was also used, after the field tests, in order to reproduce the mean working conditions of fuel delivery and measured p.t.o. and engine speed. In addition to the power required by the sowing machines, directly measured by a torque meter, this simulation aimed at evaluating the total torque and power provided by the engine and the corresponding fuel consumption.

The tests were carried out at CRA-ING of Monterotondo (Rome). The fields were flat and had clay-loam texture. Before the tests, in each plot the following characteristics and parameters were defined: soil granulometry, water contents (referred to the dry soil), bulk density, resistance to penetration - Cone Index (CI) - in the layer corresponding to the working depth. Soil characterization also included the determination of the cover index by crop residues and weeds (in the surface layer of untilled plots) and the surface roughness (in previously tilled soils).

The instrumental system used in the tests with passive implements consisted of: a digital encoder mounted on the axis of a rear drive wheel of the tractor, allowing slip calculation during the work; a mono-axial load cell (tension and compression), with full scale of 98 kN, housed in a special tow bar, capable of preventing transversal stress. It measures the force of traction between a dynamometric vehicle and the tractor-implement system that is pulled with gear in neutral, at the same working velocity. The test is made both with the implement raised and working, in order to calculate the net traction force by the difference between the two values. For operations with equipment operated by tractor power take off (PTO), in addition to the sensors first mentioned, the PTO was equipped with a torque meter, with a full scale of 3 kNm, for the measurement of the torque and speed during the work, necessary for the calculation of the required power.

The data of the most significant operating parameters have been collected by an integrated system based on two units, a field unit and a support unit (Watts and Longstaff, 1989; Al Janobi, 2000). The field unit is represented by the tractor (equipped with transducers and a PC equipped with a PCI card for the real time acquisition of the data and LCD monitors) and a photocell system indicating the start and stop of the tests on the 100 m reference distance. Transducer signals were recorded at a scan rate of 10 Hz. The support unit consists of a van equipped as a mobile laboratory: during the tests it is

parked on the edge of the field. Its PC is in communication with the field unit's PC by means of a radio-modem system, exchanging data and allowing to monitor the behaviour of critical parameters and the efficiency of the instruments (Fanigliulo et al., 2004).
The surface roughness index and the working depth have been determined, transversally to the direction of work, by means of a profile-meter, consisting of a laser sensor that measures its distance to the ground as it moves on a metallic horizontal rail across the tilled strip. A personal computer collects and processes the data (range of reading: 10 mm) (Römkens et al., 1988). Comparing the profiles observed in the same point before and after the passage of the implement, provides the roughness index (based on the calculation of the standard deviation, σ, of the heights detected) and the different levels of the untilled surface, the surface after tillage and the bottom of the tilled layer.
The Cone Index has been determined by means of a penetrometer realized in accordance with the standard ASAE S313.2 (1997). The coverage index has been determined by means of an image analysis technique that, through specific software, can detect and quantify the areas covered by biomass.
As for the testing conditions, different tillage methods were considered, with the aim of preparing the soil for maize sowing with a pneumatic precision drill. Two traditional soil tillage methods for the sowing in spring were considered. The first method (thesis A) consisted of a main tillage at medium depth, performed by a three-furrow reversible plough and followed by soil refinement with a rotary harrow. The second method (thesis B), is similar, but a disk harrow was used instead of the rotary harrow. As to conservation techniques, in the case of spring sowing, two methods were considered, both based on minimum tillage with a combined cultivator and a surface refinement made in one case, with a rotary harrow (thesis C) and with a disk harrow in the other (thesis E). In the case of maize sowing in summer, succeeding a crop of wheat, a sequence of operation consisting of a passage with a flail chopper, for the chopping of crop residues, and a subsequent tillage with a disk harrow (thesis D) was considered.
During the tests, several parameters were measured in order to obtain indication of the operational performances of the machines, according to test protocol ENAMA No. 03. Some of them are directly measured, manually by the instruments described above, such as wheel speed, force of traction, torque, interval of time, length. These are used for calculating other significant parameters, such as velocity, slip, power, fuel consumption, energy requirements, working efficiency, working time and capacity.
Preliminary tests were conducted with the aim of finding the most correct adjustment of the tractor-implement system (working velocity and gearbox ratio of the tractor, working depth) considering soil characteristics and workability. Three replications have been made for every adjustment. All measurements referred to a reference distance of 100 m.

RESULTS The tests provided a series of data that accurately describe the performance of each machine and the results of their combination. Table 2 shows the average values resulting from the measurements of the main dynamic-energetic parameters referred to each tractor-implement coupling.

Table 2.Main average values of the main dynamic-energetic parameters referred to each operating machine coupled to the same tractor.

Parameters	Three furrow, plough	Rotary harrow	Precision drill	Flail chopper	Disks harrow	Combined cultivator
Actual working speed (km h^{-1})	4.67	3.48	7.78	6.34	7.32	7.75
Actual working time (h ha^{-1})	1.10	0.73	0.22	0.26	0.32	0.33
Operative working time (h ha^{-1})	1.73	0.84	0.42	0.33	0.52	0.51
Operative working capacity (ha h^{-1})	0.58	1.19	3.53	3.03	1.93	1.97
Fuel consumption per hour (kg h^{-1})	33.7	23.9	15.83	36.1	27.3	26.0
Fuel consumption per surface unit (kg ha^{-1})	37.2	17.4	3.4	9.3	8.8	8.6
Force of traction (kN)	67.3	10.7	0.6	-	33.4	28.5
Power required for the traction (kW)	87.2	10.4	13.0	-	68.0	61.3
P.t.o. speed (min^{-1})	-	1071	537	1131	-	-
Torque at the p.t.o. (daNm)	-	35.9	7.7	94.5	-	-
Power at the p.t.o. (kW)	-	40.3	5.1	111.9	-	-
Total power provided by the engine (kW)	131.2	91.9	60.0	157.1	101.4	90.5
Energy requirement per surface unit (MJ ha^{-1})	521	240	47	146	117	107
Energy requirement per volume unit (MJ $10^{-3}m^{-3}$)	117	126	-	-	98	134
Slip (%)	20.8	10.3	3.3	-	10.7	6.4

These data are indicative of very compact and tenacious soil conditions. Considering the single operation, the analysis of the data shows that the higher demand for energy per surface unit (MJ ha^{-1}) were observed for ploughing and for surface refinement with the rotary harrow (determined by the wide work front and by the low working velocity), while the energy required per unit of volume of soil moved (MJ 10^{-3} m^{-3}) resulted higher for the combined cultivator and for the rotary harrow.

On the basis of the indications in Table 2 and considering the previously described traditional and conservative tillage methods, it has been possible to obtain, the amount of energy, fuel and work (working time) required during each applied method. The data are shown in Table 3.

Table 3. Comparison of the operative parameters between traditional and conservative tillage lines.

Parameters	Thesis A	Thesis B	Thesis C	Thesis E	Thesis D
Actual working time (h ha^{-1})	2.05	1.64	1.28	0.80	0.87
Operative working time (h ha^{-1})	2.99	2.67	1.77	1.27	1.45
Fuel consumption per surface unit (kg ha^{-1})	58.0	49.4	29.4	21.5	20.8
Energy requirement per surface unit (MJ ha^{-1})	808	685	394	310	271
Energy requirement per volume unit (MJ 10^{-3} m^{-3})	243	215	260	98	232

In the change from traditional tillage techniques to progressively more conservative methods, a gradual decline was noticed in all considered parameters in Table 3, except for the energy requirements referred to 1000 m^3 of soil that shows a variable trend. Under real conditions, it can be considered rather marginal. Although for some "conservative" machines it can reach high values with a low impact due to the nature of conservative techniques, aiming at increasing light and superficial operations on the soil instead of heavy and deep interventions. Any evaluation should therefore consider, the surface unit as the reference parameter in the comparison of the working time, fuel consumption, energy requirements between the different tillage methods. According to the needs and characteristics of each farm, it becomes possible to choose the method that, is more capable of reducing the incidence of some parameters while maintaining satisfactory production levels. Finally, the diagram in fig. 1 shows the percentage reductions of the values reported in Table 3 obtainable moving towards more conservative methods, compared to the baseline represented by the more traditional method of mechanization (first from left).

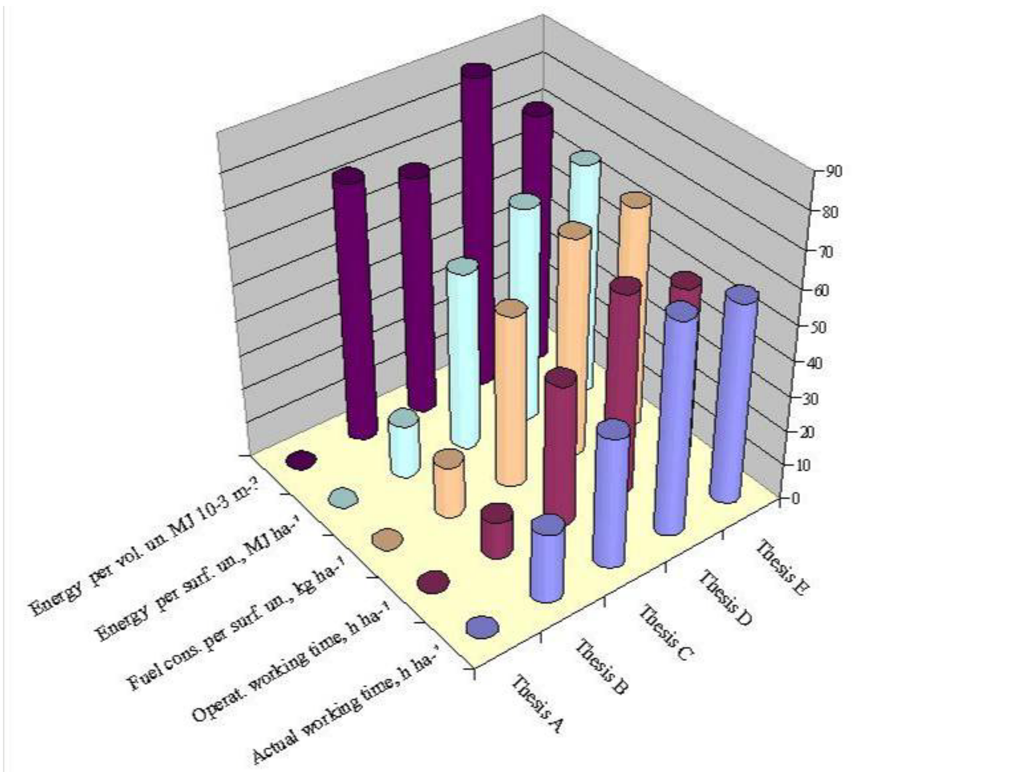

Figure 1. Comparing percentage reduction of the operative parameters from traditional methods to conservative working methods (the method “plough + rotary harrow + sowing is reference and correspond to a percentage reduction of zero for all considered parameters).

CONCLUSIONS The introduction of conservative tillage techniques of some important parameters, such as working time, energy request and fuel consumption, referred to the surface unit, keeping the productivity at satisfactory levels can contribute to significant reduction of the incidence, on farming activities.

The correct application of conservative techniques depends on soil characteristics. These determine the choice of the most suitable tillage method and, as a consequence, the amount of energy savings and production level. Conservative tillage techniques have long been widespread in large areas of Northern Italy and Northern Europe, characterized by light soil. The benefits from their introduction on more compact soils, typical of Central Italy, could be even greater, but different aspects of their use must be carefully evaluated, concerning the choice of the most proper techniques and the time interval (no. of years). The choice of the correct crops and rotation systems; new possibilities for the marginal areas; the trend of productivity over the years, is a consequence of agronomical, soil and environmental considerations, due to erosion vs. excessive soil compaction, and possible increase in the use of herbicides.

From a mechanical point of view, it is possible to obtain the assessment of the main parameters characterizing different combinations of operating machines, with a high degree of detail and accuracy, by applying rigorous test methodologies and modern equipment and instruments suitably developed. The paper reported some clear examples on the matter and the approach described could represent a significant contribution, for evaluating the possibilities of a more widespread diffusion of conservative techniques.

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