Original scientific paper

A Single-pass Reduced Tillage Technique for the Establishment of Short-Rotation Poplar (*Populus* spp.) Plantations

Alberto Assirelli, Enrico Santangelo, Raffaele Spinelli, Luigi Pari

Abstract

*In Italy, there has been a significant increase of the areas cultivated with short-rotation forestry (SRF) poplar (*Populus *spp.) for the production of lignocellulosic biomass. This species has been generally introduced on soils managed with conventional farming practices that led to the formation of a hardpan. This constitutes a serious obstacle for root development and water availability, which affect the successful establishment of the plantation. To this end the Unit of Agricultural Engineering of the Agricultural Research Council (CRA-ING) has developed a new system for reduced tillage (*RT*), to be used during the establishment of SRF poplar. This new system aims at breaking the tillage pan and at reducing both traffic intensity and site preparation cost. A new machine has been developed, which is based on a commercial rotary plough, suitably modified by adding a shank subsoiler. This machine can perform both deep soil ripping and surface ploughing in a single pass, treating narrow strips where poplar cuttings are to be planted. The study compared conventional tillage (*CT*) with *RT*, showing that latter allowed a dramatic reduction of the number of field operations and of all related problems, while creating better conditions for poplar rooting without meaningful effects on yield.*

Keywords: poplar, short rotation forestry, soil tillage, hardpan

1. Introduction

Over the past 20 years, the supply of energy wood from Short Rotation Forestry (*SRF*) has increased dramatically. *SRF* stands are very dense (6000–7000 trees/ha) tree plantations intensely managed and harvested every 2 to 5 years. Among the species suitable for *SRF*, poplar (*Populus* ssp.) has shown a very high potential for biomass production, favoured by easy propagation and establishment, fast growth and a low demand for fertilizer and pesticide applications, compared to conventional farming.

In Italy, the establishment of *SRF* poplar has been promoted by Regional Governments through attractive grant schemes, which has led to a significant increase of the areas dedicated to *SRF*. The new plantations have spread from Northern Italy (where Lombardia is the region with the largest acreage) to the Central regions, such as Emilia Romagna, Toscana, Umbria, Marche, Abruzzo and Lazio (Salvati et al. 2007). Since the Regional Programs for Rural Development favour the local supply of thermoelectric power plants, *SRF* plantations have been established as close as possible to the user plants, in order to reduce the cost of delivery.

This has led to the introduction of poplar to areas that are somewhat less suited to its cultivation, where previous farming practices involved the use of heavy machines and the recurring application of deep ploughing. Such soil management techniques generally determine the formation of a tillage pan, which represents a serious obstacle to the development of poplar root systems. The presence of a compacted soil horizon hinders root penetration and represents a severe risk factor, with adverse effects on both survival and growth. In addition, the presence of a hardpan reduces water availability, which is especially harmful during dry periods, and when irrigation is not a cost-effective option. Water availability is one of the main factors affecting the success of *SRF* poplar in the Po valley and in Central Italy, where irrigation should be considered, when trying to avoid yield losses during dry years (Bergante et al. 2010).

Beside all agronomic considerations, economic and energy issues should be analyzed, since site preparation accounts for about one third of the total production cost of a *SRF* poplar in Italy (Manzone et al. 2009). The establishment phase begins with site preparation and extends until full growth is achieved, and it is critical for the success of *SRF* investments. A good start strongly affects long-term production and sustainability. If survival rates at the end of the first year are below 80%, then the establishment is considered unsuccessful, and a low biomass production in the first year will detract from the overall performance of the crop. Financial success can be achieved by reducing establishment cost, without compromising initial survival and growth (Volk et al. 2002). This is especially true for crops like *SRF* poplar, where financial performance is conditioned by the low price of the final product, which is capped by global competition. For this reason, Italian poplar growers need to reduce production costs, maximize biomass yields and minimize work and material inputs.

SRF poplar plantations require a different approach than developed for conventional farming and especially a dramatic reduction of soil tillage operations (Khale et al. 2010, Culshaw and Stokes 1995).

Several technical operations are commonly carried out for soil preparation before establishing a poplar plantation. Currently, the most popular are: ploughing followed by two disc passes; deep ploughing (0.7–1 m) followed by one or two harrowings; and surface ploughing (0.3–0.4 m) followed by deep ripping (Anderson et al. 1983, Zoralioglu and Kocar 1996, Facciotto 1998). All of these techniques require several passes, with a deep impact on soil structure (compaction), a substantial increase of the production costs, a high energy demand and the accelerated wear of available machinery. Earlier studies have already proposed reduced (conservation) tillage techniques combined with herbicide treatments (Hansen et al. 1984, Mitchell et al. 1999), but these solutions incur the disadvantage of requiring additional chemical inputs for weed control.

On the other hand, SRF have been demonstrated to have a positive effect on agricultural soils, by reducing water runoff rates and the amount of soil losses due to water erosion, and by enhancing CO_2 sequestration and the soil organic matter content (Khale et al. 2010, Kort et al. 1998). Therefore, combining *SRF* establishment with new soil preparation techniques that are even more respectful of soil development could help meeting the EU soil protection objectives (Commission of the European Communities 2006).

New soil preparation techniques that minimize traffic-induced soil compaction would improve the soil physical properties and stimulate root development. For this reason, CRA-ING developed a prototype tiller for reducing both soil impact and site preparation cost. The new machine was obtained by modifying a commercial rotary plough, a machine already known for its good work performance (Pezzi 2004). This study presents the comparative tests of conventional tillage (*CT*) performed with multiple machines and passes, and reduced tillage (*RT*) performed in a single pass with the new machine. With the new machine, shallow ploughing and deep ripping are applied in a single pass to narrow bands, where poplar cuttings are going to be planted. In contrast, *CT* requires three separate passes (ripping, ploughing and harrowing) and is applied to all the field surface. Therefore, *RT* obtains a dramatic reduction of field traffic, soil loading and time consumption. On the other hand, the results on plant survival and growth are uncertain. Therefore, the goal of this study was to compare *CT* and *RT* for these concerns:

⇒ time consumption and soil preparation cost;
⇒ plant survival;
⇒ plant growth.

2. Material and methods

2.1 Site description and experimental design

The study was conducted between September 2007 and October 2008 in Vergiano (44°02′N–12°29′E, 36 m a.s.l.), near the city of Rimini, Italy. The soil was a silty clay loam type with physical and chemical properties: 21% sand, 39% silt, 40% clay; pH 8.1; 2.42% organic matter; 1.53% total nitrogen; 11 ppm available P; 489 ppm exchangeable K and a C:N ratio of 9.17.

A cultivation of Italian chicory for seed production preceded the plantation of poplar. As a result, before performing the tillage (conventional or reduced), the soil was uniformly covered by this specie.

Planting was carried out on 28 February 2008 using a semi-automatic planter. Planting material consisted of 22 cm long poplar cuttings, with diameter ranging between 10 and 25 mm. The cuttings had been stored in a fridge at 3–4°C before planting. Two poplar clones were tested: AF2 and Monviso®. The AF2 clone belongs to the hybrid species *Populus* x *canadensis* Moench, deriving from a cross between *P. deltoids* and *P. nigra*.

Table 1 Dimensional features of the machines used in the study

Operation	Machine	Make/Model	Power, CV	Total weight, Mg	Working data	
					Depth, m	Width, m
Conventional Tillage						
Subsoiling	Tractor	John Deere 7810	185	6.74	0.5	–
	Subsoiler	Rinieri	–	0.87	–	–
Ploughing	Tractor	John Deere 7810	185	6.74	–	–
	Reversible two-share plough	Mattioli	–	1.30	0.4	–
First harrowing	Tractor	John Deere 6400	100	4.63	–	–
	Rotary harrow	Maschio 3000	–	1.01	–	3
Second harrowing	Tractor	John Deere 7810	185	6.74	–	–
	Spring harrow	Fraternali	–	1.08	0.25	3
Reduced Tillage						
	Tractor	John Deere 3050	115	5.54	–	–
	Falc Land 1500 modified	Rotary lances plus central ripping tool	–	1.90	0.84	1.5 (3)

The Monviso clone is a more complex three-way crossing of *P*. x *generosa* A. Henry x *P*. *nigra* L., where *P*. x *generosa* is a crossing of *P*. *deltoides* x *P*. *trichocarpa*.

For each clone, two different soil preparation techniques (*CT* and *RT*) were compared. Chemical weeding was applied shortly after planting using oxyfluorfen (at a rate of 1 l/ha), pendimethalin (2.5 l/ha) and glufosinate ammonio (3 l/ha). Since during the experiment no crop diseases were detected, no pesticide was applied. No fertilizers were applied, either.

The experiment was a split-plot design with the main plot being the two soil preparations and the subplot the clones. Cuttings were planted with an interrow distance of 3 m and a space of 0.57 m along the rows (5800 cuttings/ha). Subplots consisted of two rows with a length of 350 m, containing 614 plants. The whole experimental design was completed with two border rows. The total area invested was 1.05 ha.

2.2 Machine characteristics and operations

The main characteristics of the machines used for the comparison are reported in Table 1.

The prototype was developed in cooperation between CRA-ING and Falc, a local machine manufacturer based in Faenza (Ravenna, Italy). The new machine was obtained by modifying the standard Land model rotary plough, produced by Falc. The machine featured 12 lances mounted on a horizontal axis with

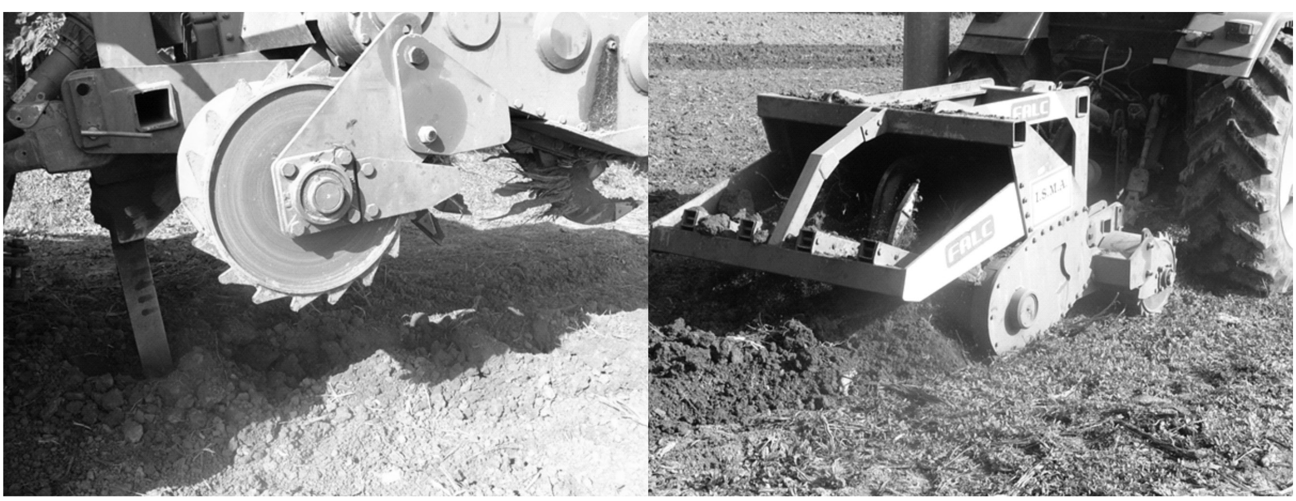

Fig. 1 Falc/CRA-ING prototype: rotary apparatus and ripping tool (left); the rotary plough during the work (right)

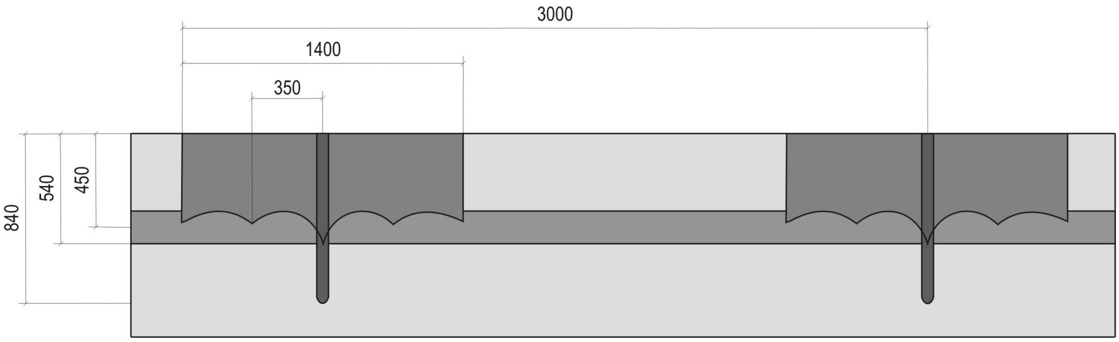

Fig. 2 Diagram showing the position of the vertical blade performing the soil refinement

three sectors, spaced 35 cm, each comprising four lances. The working width of the axis was 1.5 m, the central and the lateral sectors reaching a depth of 55 and 45 cm, respectively. CRA-ING modified the rotary plough by applying a vertical blade subsoiler in front of the support mast, for ripping the worked area to a depth of 80 cm. The blade in front of the work area of the rotary lances was fixed with a trunnion that allowed folding it during transportation. The blade is adjustable to allow for setting the working depth as needed. In this way, the original work of the rotary plough was integrated by a subsoiling action for breaking the tillage hardpan (Fig. 1 and Fig. 2).

The site preparation treatments were applied on the following dates:

⇒ *RT*: one pass on September 16th 2007;

⇒ *CT*: subsoiling on August 30th 2007; ploughing on September 4th 2007; first harrowing on September 10th 2007; second harrowing on February 25th 2008;

⇒ On February 28th 2008, the field was planted with poplar cuttings.

2.3 Climatic conditions, work productivity, plant survival and growth

The climatic conditions were monitored throughout the study by means of a weather station placed on site and properly equipped for the purpose. All operations were timed according to the CIOSTA (Comitè International d'Organisation Scientifique du Travail en Agriculture) rules, and to the recommendations issued by the Italian Association of Agricultural Engineering (AIIA). Machines cost was estimated with the method reported by Baraldi and Capelli (1973).

The effect of soil preparation technique was determined by counting the number of successfully established cuttings on the whole experimental field, and by measuring plant height on a sub-sample of 35 plants per row after 4 and 8 months from planting (June and October 2008). To avoid edge effects, they were excluded from the reliefs of the first 27 plants for each side choosing the 35 plants per row by measuring 1 plant every 16.

3. Results and discussion

3.1 Rooting, growth and survival

At plantation, the poplar cuttings must find the most suitable physical conditions for a fast rooting and suitable availability of water and nutrients. The promotion of a fast deepening of the roots in the soil layers below the hardpan (frequently present in the heavy soils of North and Central Italy), increases the rate of plant survival and allows growth when irrigation is not an option.

After spring planting, the cuttings benefited from mild temperatures that grew progressively higher as summer approached. The moisture condition of the soil was good due to the supply of winter rainfall (Fig. 3). The cuttings rooted well and developed homogenously as can be inferred by the plant height detected four (June) and eight (October) months after establishment (Fig. 4). The lack of statistical differences between the two treatments demonstrates their equivalence in terms of plant development. Therefore, it can be safely stated that *RT* does not cause any reduction of plant survival or growth compared with *CT*.

Four months after the transplant when the poplar cuttings were rooted, a check of the weeds present in the experimental field revealed the predominance of three species: perennial ryegrass (*Lolium perenne* L.), field bindweed (*Convolvulus arvensis* L.) and creeping thistle (*Cirsium arvense* (L.) Scop.). The ryegrass and the field bindweed grew preferably along the poplar rows; in some cases, the latter extended its procumbent stems in the inter-row. On the other hand, in some

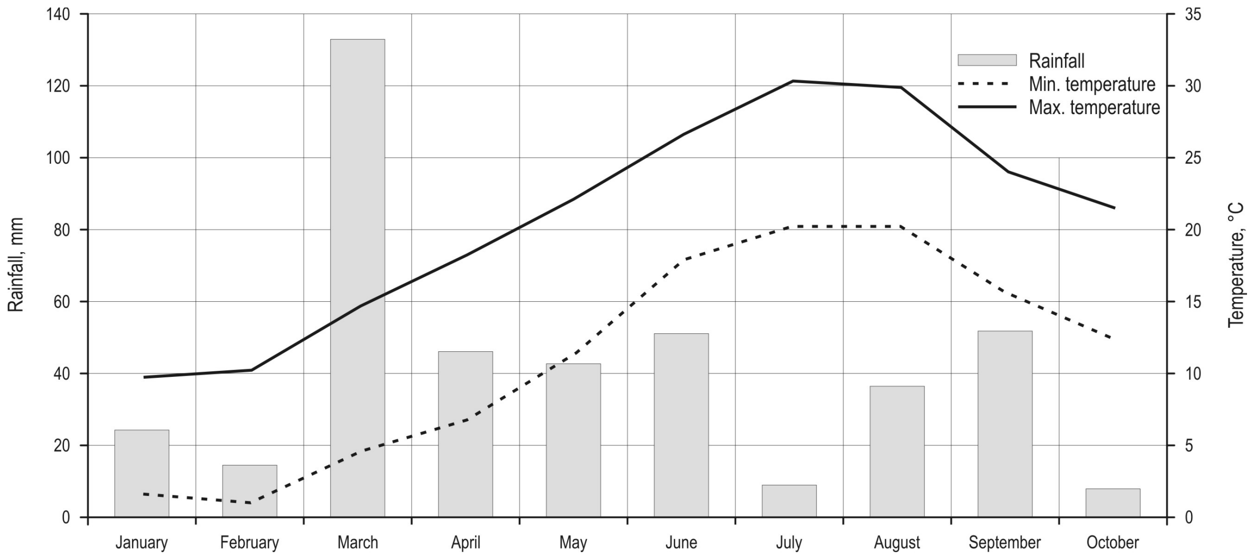

Fig. 3 Rainfall and average temperatures at the site of the experimental trial during period of observation

scattered areas, the creeping thistle had colonized the space along and between the rows. However, compared to the pre-planting state, where the field was a continuous lawn, after the treatments (*CT* and *RT*), the presence of weed was localized almost exclusively along the rows, without significant differences between the *CT* and the *RT*.

A few months after planting, the genotype effect was very clear. Monviso sprouts were generally shorter than 1 m, whereas about 25% of the AF2 sprouts were taller than 1 m (Fig. 5a and Fig. 5b). In October, the effect of tillage also started to show: Monviso sprouts, grown on the plots treated with *RT*, were distributed for almost 90% in the upper height classes, against 58% of the sprouts treated with *CT*. Even if less evident, the same difference was also visible for clone AF2, where 100% of the sprouts, treated with *RT*, were distributed in the four upper classes, while those managed with *CT* reached these same classes for 92% only (Fig. 5c and Fig. 5d).

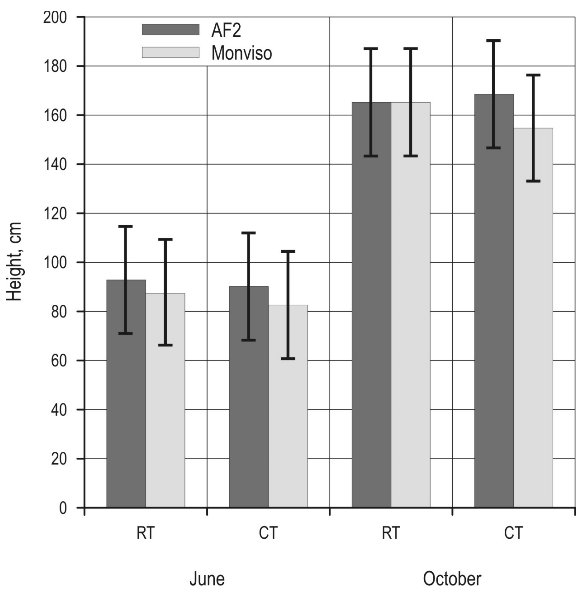

Fig. 4 Height of poplar AF2 and Monviso clones measured four (June) and eight (October) months after transplant and treated with *RT* (reduced tillage) or *CT* (conventional tillage); data are the mean of thirty-five trees ±S.E.

A very important result concerns survival rate (Fig. 6), because the cuttings of both clones showed a higher percentage of survival when *RT* was used, and these differences reached statistical significance for the clone Monviso. The structural conditions created by the repeated passages operated with *CT* were not favourable for successful rooting. In contrast, the concurrent actions of soil breaking, soil turning and ripping obtained with the prototype resulted in a breaking of the hardpan, a more homogeneous structuring of topsoil and an opening of the subsoil. Such results are in contrast with those published by Balbuena et al. (2002), who studied the effect of traffic intensity on poplar plantations and showed that the height of poplar shoots was not affected by the traffic intensity during harvesting. However, the same Authors showed that traffic intensity did affect shoot mortality, which increased by 42% and 51%, respectively, on soils receiving 5 and 10 machine passages. (Balbuena et al. 2002).

It should be noted that the influence of both subsoiling and surface ploughing on plant survival during dry periods is favourable, if irrigation is not supplied. This

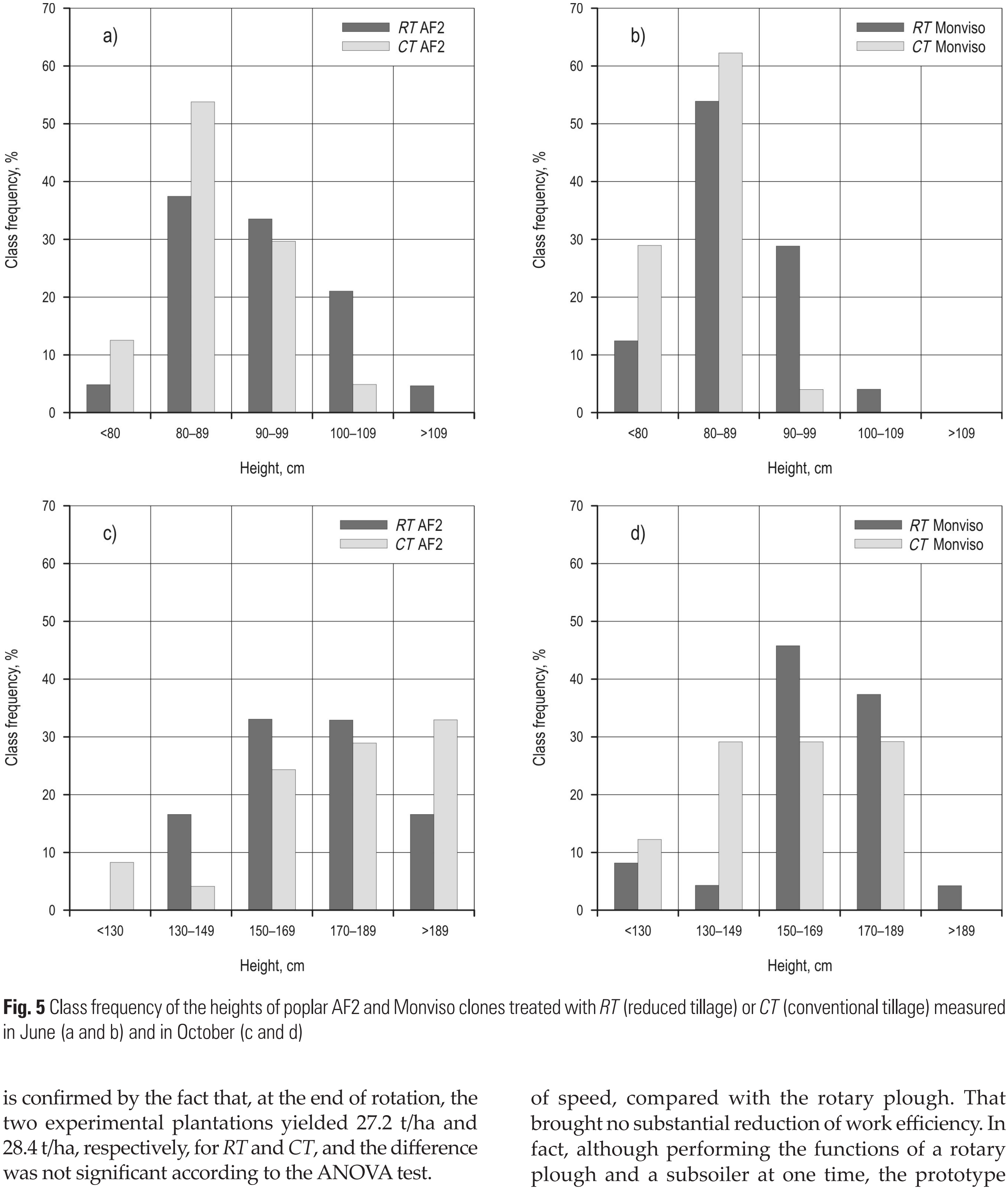

Fig. 5 Class frequency of the heights of poplar AF2 and Monviso clones treated with *RT* (reduced tillage) or *CT* (conventional tillage) measured in June (a and b) and in October (c and d)

is confirmed by the fact that, at the end of rotation, the two experimental plantations yielded 27.2 t/ha and 28.4 t/ha, respectively, for *RT* and *CT*, and the difference was not significant according to the ANOVA test.

3.2 Working capacity and economic evaluation

Working speed for the prototype was halfway between that of the deep plough and of the rotary plough (Table 2). Considering the braking effect of the vertical ripper blade, one could expect the observed reduction of speed, compared with the rotary plough. That brought no substantial reduction of work efficiency. In fact, although performing the functions of a rotary plough and a subsoiler at one time, the prototype showed an effective work time that was lower than that of a rotary harrow alone, and registered reduced delays for turning (Fig. 7). Considering the speed and the actual working width given from the inter-row space of transplants (3 m), the effective working capacity was 0.54 ha/h.

Table 2 Operative data of the machines employed

	Reduced Tillage	Conventional Tillage			
	Falc Land 1500 modified	Subsoiler	Reversible two-share plow	Rotary harrow	Spring harrow
Effective speed, km/h	1.91	2.66	1.51	2.20	4.28
Operative speed, km/h	1.80	2.48	1.37	2.09	4.00
Working capacity, ha/h	0.54	0.75	0.41	0.63	1.20
Effective work time, %	94.93	94.12	91.38	96.17	93.10
Delays, %	5.07	5.88	8.62	3.83	6.90
Total work time, %	100.00	100.00	100.00	100.00	100.00

By analyzing in detail the figures for delays (Fig. 7), the prototype showed good flexibility and manoeuvrability in the reduction of turning time (3.5% of the total working time). On the other hand, it also required more time for field adjustments than the two harrows and the reversible plough.

From the standpoint of environmental impact, it is clear that *RT* produced the same agronomic result with a reduction of fuel use and soil loading (Fig. 8). *RT* allowed saving 80.4 l of diesel per ha (103.8 l/ha being the sum of fuel consumption for *CT* vs 23.5 l/ha for *RT*). Therefore, *RT* allowed reducing fuel consumption by more than 4 times. Likewise, soil loading amounted to 7.4 Mg for *RT* and 29.0 Mg for *CT* (Table 3). *RT* showed a ratio trampled/worked area equal to the first harrowing and, although with a relatively high weight of the unit, it achieved a noteworthy reduction of traffic intensity.

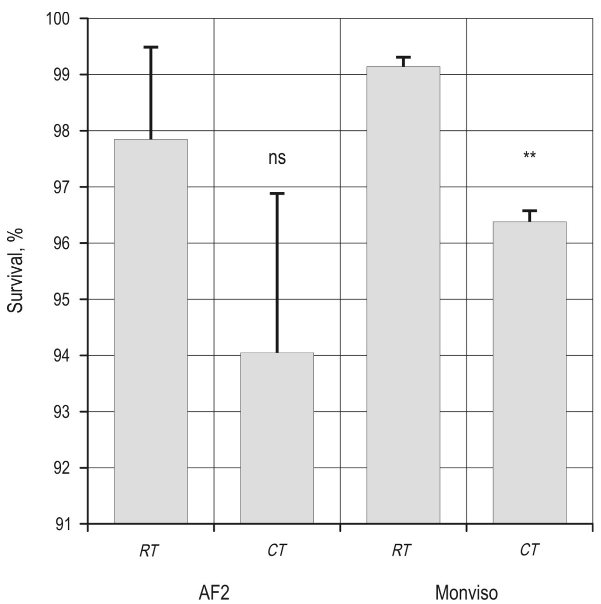

Fig. 6 Percentage of cuttings survival (%±*SE*) of AF2 and Monviso clones registered two months (April) after the transplant and treated with *RT* (reduced tillage) or *CT* (conventional tillage); significant differences between treatment within each clone were determined by Student's *t*-test; $**p<0.001$ probability levels, is not significant

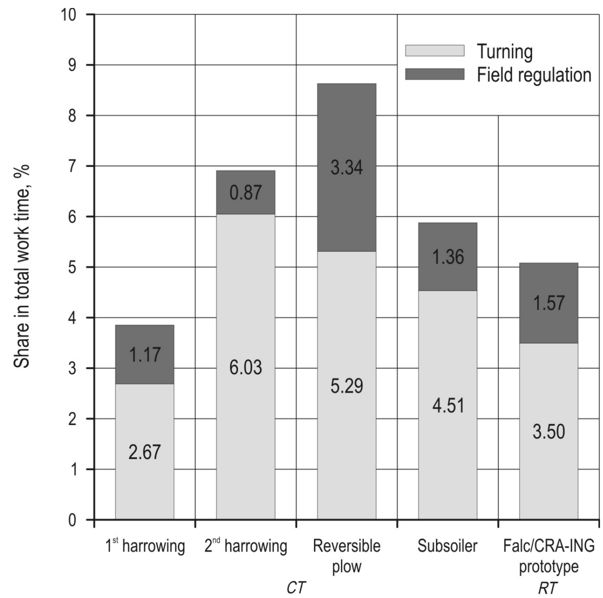

Fig. 7 Detailed delays registered for soil preparation of poplar planting by *CT* and *RT*

The hourly cost of the prototype appeared in line with the values calculated for the other treatments, with the only exception of the rotary harrow (Table 4). Taking into account its working capacity, the cost of *RT* was rather high (109 €/ha), but lower than that observed for ploughing (139 €/ha). However, since the *RT* soil preparation only involves the use of the prototype, the cost per unit area is limited to this intervention, with a reduction of 65% compared to *CT*.

Table 3 Soil surface exposed to trampling by tilling machines used during the trial

	Tyre width of the tractor, mm		Total weight of the unit, Mg	Width		
	Front	Rear		Trampled[a], m	Worked, m	Ratio trampled/worked, %
Conventional Tillage						
Subsoiling	540	710	7.60	1.42	2.0	71.0
Ploughing	540	710	8.04	1.42	1.2	118.3
First harrowing	380	420	5.64	0.84	3.0	28.0
Second harrowing	540	710	7.82	1.42	3.0	47.3
Reduced tillage						
Falc Land 1500	380	420	7.44	0.84	3.0	28.0

[a] Calculated for the rear tires

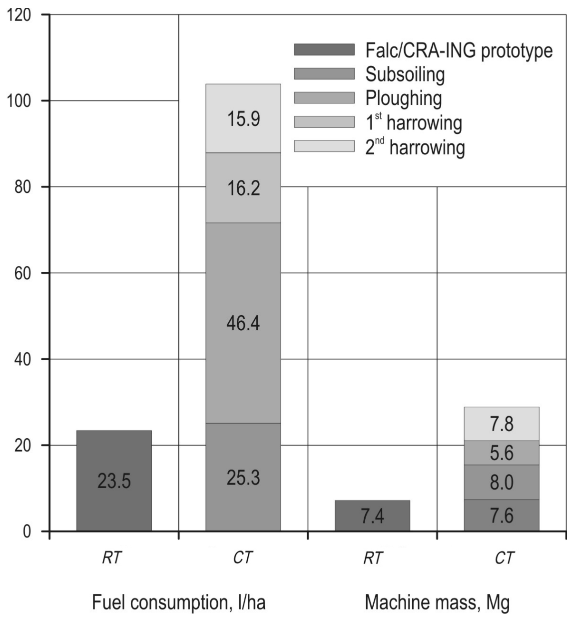

Fig. 8 Fuel consumption (l/ha) and machine mass (Mg) ascribed to *RT* and *CT*

4. Conclusions

The two tillage systems (conventional vs reduced tillage) compared in this work showed deep differences in terms of machine productivity and economic performance. The working capacity of the Falc/CRA-ING prototype was halfway between the ploughing and the first harrowing, but its strength lies in the possibility of reducing the number of operations in the field, and all related problems, such as: soil compaction, need of finding the soil in good conditions for machine accessibility, reduction of emission due to cultural techniques, and fuel consumption.

Table 4 Economic aspects of the tilling machines analyzed during the trial

	Hourly cost, €/h	Cost per unit area, €/ha
Conventional Tillage		
Subsoiling	54.23	72.31
Ploughing	57.17	139.44
First harrowing	40.20	63.81
Second harrowing	53.87	44.89
Reduced tillage		
Falc Land 1500 modified	54.97	109.46

The prototype revealed that it was worth combining a deep subsoiler, requiring considerable traction effort, with a rotary plough, which used the energy supplied by the power take-off and gave a helpful boost to machine advancement. Compared to *CT*, *RT* allowed a similar growth of the cuttings while improving their survival. This was probably due to the easier root development that derived from positioning the cuttings on the deep cracking, which is not always feasible when adopting *CT*. The utilization of this new technique makes it possible to introduce SRF poplar to new areas of North and Central Italy where the conventional farming practices have caused the formation of a hardpan, which may negatively affect the plant establishment and biomass yields.

Single pass soil preparation is advantageous from the agronomic, economic and environmental point of view, and represents a valid alternative to time- and energy-consuming traditional practices.

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