Energy and economic evaluation of a poplar plantation for woodchips production in Italy

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Abstract

In Europe, farmers prefer the very Short Rotation Coppice (vSRC) cultivation model, with a very high plant density (5500-14000 p ha^{-1}) and a harvesting cycle of 1-4 years; while in Italy, recently, the farmers prefer the Short Rotation Coppice (SRC) method, with a high plant density (1000-2000 p ha^{-1}) and a harvesting cycle of 5-7 years. This is because the most recent poplar hybrids have enhanced productivity and improved the biomass quality (calorific value), as a result of a better wood/bark ratio.

In order to evaluate, from the energy and economic point of view, a poplar SRC, in the river Po Valley, an *ad hoc* study was made and a specific model was developed.

On the basis of this cultivation technique, an energy and economic evaluation of a poplar SRC in Northern Italy was realised. In detail, were considered data of poplar growth, in a plantation for the production of 6 year whips, in Western Po Valley, considering a SRC duration of 6 years and a biomass (15 Mg ha^{-1} dry matter -D.M. per year) harvest at the end of cycle (6 years). In this computing system it was pointed out that the SRC is very interesting from an energy point of view, since the output/input ratio results to be higher than 18. The same in not true for the poplar SRC from an economic point of view. In order to obtain economic SRC sustainability, the biomass price should be at least 115 € Mg^{-1} D.M. A large biomass diffusion will be possible only with an increase of the biomass market value, or with economic sustain for its production.

Keywords

Short rotation coppice; biomass production; economic evaluation; energy consumption

Introduction

The cultivation of crops for biomass production on good, arable soils allows to increase the energy production, with many advantages from the environmental point of view. This solution increases the farmers' revenues and leads to advantages for the environment [1,2,3,4,5].

In the last 10 years, the cultivation of crops for biomass production has been inserted in the cultural plans of several farms, particularly in Northern Italy; farmers take advantage of their low input requirement and the added possibility of exploiting set-aside areas [6]. In Italy, there are two different methods of cultivation: very Short Rotation Coppice (vSRC), with very high density, from 5,500 to 14,000 plants ha^{-1} and harvested with a rotation period of 1-4 years and Short Rotation Coppice (SRC) with a high density from 1,000 to 2,000 plants ha^{-1} and harvested with a rotation of 5-7 years [7,8]. In Europe, the farmers prefer the vSRC cultivation model [9,10,11,12,13], while in Italy, recently, the farmers prefer the previously described SRC method, because the most recent poplar hybrids have enhanced productivity and improved the biomass quality (high calorific value), as a result of a better wood/bark ratio [14,15,16,17]. Furthermore, it is also prefered, because in the rural development plans of the main Regions of northern Italy, the establishment of this cultural model is financed.

Most of the studies carried out until now in Italy have focused only on the vSRC method, as they are more spread throughout the territory; little has been yet experienced on the SRC method [18,19].

In order to evaluate from the energy and economic point of view a poplar SRC in the river Po Valley an *ad hoc* study was made and a specific model has been developed.

Materials and methods

A series of data were collected, both in the nursery and in the poplar SRC plantation, nearby the experimental farm "MEZZI" of CRA-PLF, close to Casale Monferrato (AL), during 2006-2012 period. All the cultural operations for poplar plantation were analysed: the working time and both machines and manpower requirements were recorded on the field, in compliance with CIOSTA (Comité International d'Organisation Scientificue du Travail en Agricolture) methodology, on at least 5.000 m^2 surface areas and for periods not shorter than 2 hours [20]. The developed model allowed the determination of manpower and energy requirements, as well as the costs analysis considering different crop density and biomass production. The model considers a continuous poplar SRC plantation: the whole acreage is divided into different "modules", each corresponding to 1 year of the crop cycle, allowing to refer all costs to annuity. Regarding the economic and energetic evaluation, a 6 years rotation, with harvesting carried out at the end of the cycle and with a starting poplar plants density of 1100 for hectare was considered, with a 3.00 × 3.00 m spacing and a mean production of 15 Mg ha^{-1} D.M. $year^{-1}$ [21,22]. For all post-emergency treatment, it was supposed to use traditional tractors with 4 RM, with a maximum width of 2.2 m. In detail, for the nursery and the poplar SRC plantation it was assumed to prepare the soil with ploughing at 40 cm depth after seed bed fertilization – 500 kg ha^{-1} of 8.24.24 (N,P,K).

Secondary tillage was carried out by two harrowing interventions, while for the plantations of rods (1.20-2.00 m in length), an Allasia V1 planter was considered [23]. The cultural operations assumed for the SRC cultivation and nursery were fertilization and weed control, both necessary to allow a high production of biomass [24,25]. Finally, it was assumed to use a heavy cultivator for stumps removal (table 1-2).

For biomass harvesting, a chipper prototype Gandini Bio-harvester (purchase cost € 60,000) was used, with a tractor of 190 kW Case Magnum 260 EP (purchase cost € 170,000). The working capacity of the Gandini Bio-harvester is about 60 t h^{-1} (about 120 plants h^{-1})[26]. For the transport of the biomass in the farm (about 400 meters distant), two tractors with trailers were used. The average cost of the Gandini Bio-harvester was determined considering contractors costs.

The manpower requirement was determined considering the number of operators and the working time to carry out every cultural operation.

The energy consumption were determined considering both direct costs – fuel and lubricant consumption - and primary energy – machine, equipment and mineral fertilizer energy contents (table 3) [27]. Machine fuel consumption was determined by refilling the machine tank at the end of each working phase. The tank was refilled using a 2000 cm^3 glass pipe with 20 cm^3 graduations, corresponding to the accuracy of our measurements.

The lubricant consumption was determined in function of the fuel consumption using a specific algorithm setup by Piccarolo [28].

The human work was expressed in manpower hour requirement, for every cultural operation, but it was not considered from the energy point of view.

The economic evaluation was determined for every cultural operation considering both the machine cost and that of the production factors (fertilizers, plant protection products) (table 4).

The hourly cost rate of each machine was evaluated using the method proposed by Miyata [29], with prices updated to 2013. An annual utilization of at least 500 hours (tractor used also for other operations) was assumed for tractors, and the power requirement was calculated by taking into consideration the data recorded during experimentation and the drawbar pull and power requirement, in the different operating conditions. Labor cost was set to 18.5 € $hour^{-1}$.

Fuel cost was assumed to be 0.9 € kg (subsidized fuel for agricultural use). Also the tractor hourly cost was determined with the methodology proposed by Miyata [29].

For the evaluation of economic sustainability it was determined the Net Present Value (NPV) that indicates the difference between the total income and the total costs determined considering a biomass value of 100 € Mg^{-1}D.M. This determination was done for different costs of land and water use [30].

Results

Near 27 hours per $year^{-1}$ of manpower were required for the cultivation of one SRC hectare. The biomass harvesting required less than 45% of the total time, while the pesticides application required more than 9% (Fig. 1).

The energy consumption for the cultivation and management of 100 ha of poplar irrigated SRF is of 15.2 GJ ha^{-1} per year and represents about the 5% of the biomass energy production (about 270 GJ ha^{-1} for year). The input/output ratio is close to 18. The largest part of energetic input (44%) is linked to cultural operations, in particular at the top dressing (36% of the total energy requirement). Harvesting and biomass transport to the farm storage represents about 25% of the total energy requirements; the flood irrigation does not require any energy input (Fig. 2).

In conclusion, for arable surfaces between 50 and 200 ha, the total energy cost resulted between 4.9 and 5.2% of the energy produced.

In the total balance, the direct energy cost results to be 1.9% and the indirect energy cost the 3.0%, for a 50 ha SRC cultivation and 3.2% for a 200 ha SRC cultivation.

The production cost of the SRC with 6 year cycle resulted closely connected to both the cultivated surfaces and to the production level. Considering a biomass production of 90 Mg ha^{-1} D.M. per cycle, equivalent to about 180 Mg ha^{-1} W.B., the production cost is close to 122 € Mg^{-1} D.M. for SRC surfaces of 100 ha (Fig. 3), a value higher than the market price of wood chips (95 € Mg^{-1} D.M.) .

The cultural operations that have the higher weight on the total production costs are the “crop management operations” (near 26,9%) (Fig. 4). The most expensive are the interrow cultivations (weed control) for post-emergence treatment and the irrigation intervention; but these operations are indispensable to get a high biomass production. Besides, land use costs showed also a high incidence on the total costs. For example, considering a 100 ha SRF surface, with 15 $ha^{-1}year^{-1}$ D.M. biomass production, for every cycle and zero cost for irrigation, the biomass cost production is 113 € Mg^{-1} D.M., with land use cost of 200 € $ha^{-1}year^{-1}$. In the case of a land use cost of 400 € $ha^{-1}year^{-1}$ the biomass production cost is of 126 € Mg^{-1} D.M. The land rent cost weights upon total production cost for the 11 and 21% respectively. Considering zero the cost rate of land, the biomass production cost fluctuates from 103 € Mg^{-1} D.M. to 119 € Mg^{-1} D.M. with 50 and 300 € ha^{-1} irrigation costs respectively (Fig 5-6).

Nevertheless, it has to be considered the influence of the transport and storage costs in terms of biomass losses on the total biomass production cost. The transport cost weights upon total cost for the 2 and 15% for distances of 5 and 50 km respectively (Fig. 7).

Discussion

The poplar SRC plantation, in the considered condition, - 6 years rotations, with harvesting carried out at the end of the cycle and a production of 15 Mg ha^{-1}D.M. $year^{-1}$, - is very interesting under the energy point of view, since the output/input ratio results to be higher than 18.

This value is 5 points higher than that calculated for a vSRC by Manzone et al [17]. The better results are to be attributed at the minor energy consumption for SRC planting, because the rods preparation is less expensive compared to cuttings production and the SRC starting investment (1,700 plants ha^{-1}) is minor to vSRC plantation (6,700 plants ha^{-1}).

Furthermore, the use of rods in SRC planting reduces also the energy consumption for the weed control, because the shoots are placed at a height (50 – 120 cm) greater than that of the cuttings and they can better compete with the weeds.

The largest part of energy input (44%) is linked to cultural operations, in particular at the top dressing (36.8% of the total energy requirement) necessary to have a high biomass production (15 Mg ha^{-1}D.M. $year^{-1}$) [31] as well as to choose the most appropriate clone for the site [11].

In the total balance, the energy input per unit biomass produced is 4.1% of the energy output. This value is similar to that found in another analysis made in Sweden on willow SRC [32].

The SRC economic evaluation, differently from energy point of view, is negative because the market price of the woodchip is low respect to value of production. In fact, in order to get economic SRC sustainability, the biomass price shall be at least 115 € Mg^{-1} D.M. (€ 15 more than to currently market price).

But with this model, in 6 years trees with a diameter at breast height of 150-200 mm are grown. So the basal part of the trunk, up to 4-6 m, can be used to produce industrial wood (OSB panel, packaging) with a value higher than the one of wood chips for energy. In this case the economic balance become positive [33].

Since the tree have not a small diameter (> 150 mm), this biomass plantations offer woodchips of high quality, with high fibres content (85–90%) and favourable particle-size distribution. On the contrary, vSRC presented a high bark content (>20%) and occasionally a mediocre particle-size distribution, being often too rich in fines (>10%). These problems were especially serious with fuel derived from 1-year old vSRC sprouts [18].

A material with high bark content have a low market price because showed a low lower heating value and a high ash content [34,35,36]

Besides, it is to highlight that the rods planting is a difficult operation management due to the reduced available time (march and april) and because the planters used have a low working rate and required a high manpower [23].

Conclusions

A large SRF plantation diffusion will be possible only with an increase of the biomass market value or with economic support for the production.

At present, Italian farmer prefer the SRC cultivation model respect to that vSRC cultivation model because from tree with 6 years of age is possible to obtain wood assortment of high economic value to sell to sawmills (packaging) or for OSB panel production.

It is to underline that SRC cultivation can contribute to solve the problem of the exceeding traditional cultivations and that it is able to improve the relations between agriculture and environment. It's getting more important to find low environmental impact cultural solutions able to maximize the biomass yield by using the poplar auxometric curve.

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