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# SHORT ROTATION FORESTRY PLANTATION. AN OVERVIEW OF CULTURAL PRACTICES AND AN ECONOMIC ASSESSMENT IN CENTRAL ITALY

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*The article firstly presents an overview of main cultural practices of a 15year-rotation forestry plantation of black locust (*Robinia pseudoacacia *L.) in central Italy; secondly, it provides an economic assessment of such plantation. In doing this, we apply a sensitivity analysis of a range of input values by using the Spreadsheet Costing Model (SCM). The objective of the evaluation is to assist bioenergy managers and researchers on key aspects that could improve profitability.*

*The report concludes that SRF constitutes still a marginal reality in the national agriculture system. This is unsurprising considering the lack of initiatives for widespread use of biomass on a large scale. If this gap is filled, SRF would then be able to promise certain remuneration to the producers.*

*Key words*: black locust; Short Rotation Forestry; bioenergy; economics; sensitivity analysis.
*Parole chiave*: robinia; piantagione a ciclo breve; bioenergia; economia; analisi di sensitività.

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## 1. INTRODUCTION

Short Rotation Forestry (SRF) plantation is a specialized woody crop planned and managed to produce relatively high quantity of woody biomass in few (2-3) years. Yields of a SRF plantation vary considerably depending on the tree species and are affected by the influence of genetics, soil, climate and management on survival, competition, and vigor of the stand. Harvestable yields in temperate and Mediterranean regions of Europe range between 10 and 15 tonnes (t) of dry matter (d.m.) $ha^{-1}$ $yr^{-1}$.

The cultivation of fast-growing woody plants within SRF is worldwide gaining more and more consideration. This is mainly due to its potential of supplying biomass[1] for energy and industrial purposes, as a substitution for more energy intensive materials, such as fossil fuels and cement-based materials. Compared to annual crops, woody species grown in a SRF have higher energy densities, lower transportation costs, and reduced needs for annual inputs; these factors minimize the utilization of fossil fuels during production and thus improve the overall energy balance of the fuel.

[1]Biomass, when used in reference to renewable energy, is any biological (plant or animal) matter that can be converted to electricity or fuel. Woody biomass refers to biomass material specifically from trees and shrubs. It is most often transformed to usable energy by direct combustion, either alone or co-fired with coal; however, efforts are underway to develop methods to cost effectively convert woody material to liquid fuels



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SRF may have positive impacts on the environment and deliver additional ecosystem services in terms of carbon sequestration, biodiversity, soil quality, nutrient retention, and soil protection from wind and water erosion, landscape appearance, inland water availability and quality. Since wood products are a renewable and relatively energy efficient source of material, greenhouse gas emissions can be reduced by using wood biomass in place of more energy-intensive resources. Delivering the EU climate, biodiversity, renewable energy and rural development targets set by the EU and domestic policies is expected to enhance the establishment of SRF.

In this study we analyse the black locust SRF plantation[2] and assume that lasts 15 years and it is coppiced every 3 years, in order to have 5 rotations before the establishment of a new SRF plantation. The types of cultural practices (as depicted in §2) are used as the basis for the subsequent economic analysis.

The objective of this study is to assist bioenergy managers and researchers on key aspects that could improve profitability.

## 2. Cultivation technique

Based on the experience gained to date (Balsari *et al.,* 2002; Facciotto *et al.,*1998; Sperandio and Verani, 2000; Bisoffi and Facciotto, 2000; Facciotto and Mughini, 2003; Di Matteo *et al.,* 2011), the most significant cultivation operations that characterize a SRF plantation of black locust (*Robinia pseudoacacia* L.) are shown in Table 1.

All stages of the crop cycle, particularly the harvesting, are integrally mechanized. Plants are coppiced at regular intervals (rotations). After each harvest the new shoots re-grow from the coppice stools, starting a new rotation cycle. The time of rotation varies from 2 to 3 years, in order to produce shoots of about 4 centimeters in diameter at breast height (dbh), a dimension that best bestow to machineries typically used for harvesting (Schenone,1998). Rotations shorter than 3 years lead to reduced yields after several rotations due to physiological problems including stump aging and depletion of carbohydrate reserves, and maximum biomass productivity is expected with harvest cycles of 3 to 11 years.

### *2.1. Site selection*

The most important prerequisite to make SRF economically viable is an abundant yield. In Italy, yields from willow, poplar or black locust SRF at first harvest are expected to be in the range 7-12 oven dry tonnes per hectare per year (odt $ha^{-1}$ $yr^{-1}$) depending on site and efficiency of establishment.

### *2.2. Soil preparation*

Ground preparation for a tree crop short cycle initiates with tillage. This operation is followed by one or more steps of aging and equalization as needed depending on the soil condition of the site.

### *2.3. Planting stock and planting system*

After soil preparation, crop practices and operations initiate. The equipments used, operational capacity and, therefore, final cost of the planting out, depend largely on the species, the planting stock type and planting system selected.

Normally, in Mediterranean sites SRF crop is planted between late winter and early spring using planting material produced by specialist breeders and equipment specifically designed for the purpose.

The type of planting stock may vary depending on the final destination of the product. In biomass energy plantations of species like willow, poplar and black locust, there is now widespread use of plant cuttings, which have considerably lower cost (Balsari *et al.,* 2002).

Planting stock can be out-planted either in single row or twin-row. The row system

[2]Willow and poplar appear to be most ideal species for SRF, although different climatic conditions and topography in Italy make the black locust species a possibility for the marginal areas of the North Central hills and alluvial areas. Eucalyptus may be suitable for the temperate climate of the South.

*Table 1* – Cultivation operations of SRF black locust plantation over five rotation cycles.

| *Practices and operations per year* | *0* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* | *11* | *12* | *13* | *14* | *15* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Plant operations* | | | | | | | | | | | | | | | | |
| Tillage | X | | | | | | | | | | | | | | | |
| Harrowing | | X | | | | | | | | | | | | | | |
| Transport and distribution of fertilizers (P, K) | | X | | | | | | | | | | | | | | |
| Planting out | X | | | | | | | | | | | | | | | |
| *Cultivation practices* | | | | | | | | | | | | | | | | |
| Pest and desease control | | | X | | | X | | | X | | | X | | | X | |
| Mechanical weed control between rows | | X | | | X | | | X | | | X | | | X | | |
| Chemical weed control between rows | | X | | | X | | | X | | | X | | | X | | |
| Fertilization (N) | | | | X | | | X | | | X | | | X | | | X |
| Irrigation | | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Harvesting and transport | | | | X | | | X | | | X | | | X | | | X |
| Soil re-establishment (removal of SRF) | | | | | | | | | | | | | | | | X |

arrangement and the distance between plants on each row will define the plantation density.

Planting density will vary depending on the type of system selected. In Italy, poplar and willow plantations require a density of around 10.000 plants ha$^{-1}$. The distances between single or twin rows depend mainly on the available farm equipments and can vary from 1.80 to 2.50 meters, independently from the system row used. Distance between plants on the same row varies from 0.5 to 0.75 m.

Higher densities increase cost and create greater competition between plants which can lead to premature death of the stumps dominated. The single row system allows a better weed control, both on the row and between rows, and a lower competition among the tree stumps. The use of twin or coupled rows facilitates the mechanized harvesting but makes weed control more difficult. In any case, determining the limits of the above cited cropping systems in the different environments is a very interesting topic and is strictly linked to the used species, the site characteristics and the farm efficiency (DE FRANCHI *et al.,* 2010).

### 2.4. Fertilization

The nutrient demand of SRF plantation is minimal, especially when compared with typical agriculture annual crops. *Leguminosae* and *salicaceae* tree species, in order to maintain the fertility of the soil, proportionally need to return an amount ranging from 40 to 60 kg ha$^{-1}$ yr$^{-1}$of the 3 major nutrients: nitrogen (N), phosphorus (P), potassium (K). Phosphorus and potassium should be buried underground, while nitrogen should be distributed as dressing fertilizer starting from the second year after planting and coppicing. Such a late distribution of nitrogen is due to prevent the growth of weeds during the first planting year or in the subsequent months after coppicing, when soil is uncovered (FACCIOTTO *et. al.,* 2003).

### 2.5. Irrigation

Irrigation is a very expensive operation and could jeopardize the economic return of a SRF plantation. This is why the planting of SRF crop on any sizeable scale should be best avoided in sites where water demand is expected to exceed available supplies. Guidelines recommend that where the annual precipitation is <600 mm only a small proportion of a catchment should be planted, due to SRF using all of the effective precipitation.

### *2.6. Mechanical and chemical weed control between rows*

The main aim of these operations is minimizing weed management practices and containing their costs. Weed control primarily consists of chemical interventions, weeding and/or mechanical harrowing.

The fundamental chemical intervention is implemented immediately after planting and is a decisive practice as it protects the cuttings in the early stages of re-growth. During this crucial period, their capability to compete with weeds is weak and mechanical weeding would be harmful to their development. When the cuttings have reached a sufficient stage of development it's possible to control weeds mechanically.

The number of harrowing practices to be carried out varies depending on the seasonal patterns and the pace of growth of the plantation.

### *2.7. Pest and disease control*

The very humid microclimate that is established in the SRF, as a result of high plant density, is a favorable condition to the proliferation of many insects, including aphids, scale insects and some defoliators. Even the frequent coppicing creates stumps for wood-boring populations and favor the establishment of conditions conducive to the development of fungal parasites cortical (Facciotto *et. al.,* 1998).

### *2.8. Harvesting*

The collection of short rotation coppice can occur in two distinct systems: continuous and discontinued.

The first requires that the biomass is harvested and shredded without a separation between these two stages. The entire process is done by a single machine and the material is discharged in chips directly into the transport machine. The other system is based on separation of the phases of cutting, collecting and shredding, which can also be made with different machines at different times (Spinelli, 2000).

### *2.9. Removal of the SRF plantation and soil re-establishment*

SRF is a woody, perennial crop, the rootstock or stools remaining in the ground after harvest with new shoots emerging the following spring. A SRF plantation could be viable for up to 20 years, depending very much on the productivity of the stools, before re-planting becomes necessary.

At the end of the SRF crop, in about 10-15 years, the soil has to be re-established, bringing the ground back to the state before cultivation.

## 3. Materials and methods

There have been a significant number of studies concerning the production costs of SRF crops and their profitability (Hayes, 2009). Therefore, there are highly comprehensive, free, computer-programs available for download from the internet. The user can input a range of variables according to the specific conditions of the farm and the program will calculate expected costs.

Following the approach by Nicholas (2003), we assessed the costs of bioenergy crops. To provide a clearer understanding of which factors impact preventable costs of bioenergy crops, this paper has evaluated the sensitivity of a range of input values.

Maximal biomass production is an obvious target for making SRF economically viable. In this study we assume that yield from black locust SRF at first harvest are expected to be 10 oven dry tonnes per hectare per year ($m^3$ $ha^{-1}$ $yr^{-1}$). Figure 1 presents the evolution of the yield increase over the rotation periods. It is supposed to be zero in the first year and to reach 10 $m^3$ $ha^{-1}$ $yr^{-1}$ the second and the third year since plantation. After the first harvesting

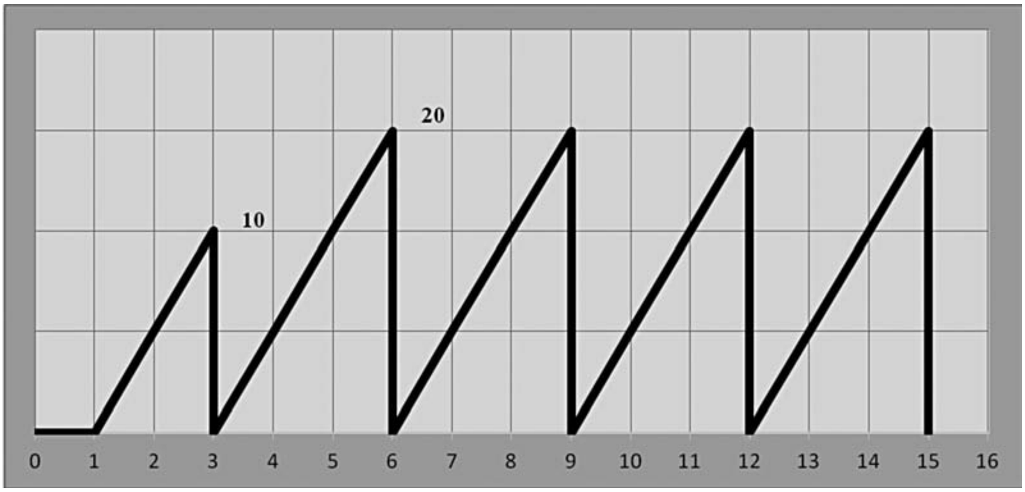


*Figure 1* – Evolution of SRF annual crop yield over the rotation periods ($m^3$ $ha^{-1}$).

yield increase gets to 20 $m^3$ $ha^{-1}$ $yr^{-1}$ for the other four cycles of rotation.

In order to assess the growing costs of the SRF bioenergy plantation a spreadsheet model has been developed, as described below.

### *3.1. The Spreadsheet Costing Model*

The Spreadsheet Costing Model (SCM)[3] is an Excel file structured in 4 spreadsheets, whose results are reported in tables of the Appendix. It is a spreadsheet module that can be used to observe the sensitivity to changes in growing costs of a SRF plantation. The initial spreadsheet comprises constant and variable values that we can use to build the model (Appendix – Table I). In our case, constant values are represented by costs of cultivation operations, whose calculation is based on a study by the University of Udine, as cited by BERTOSSI (2005), and they give an average cost per hectare of a SRF stand, as depicted in Table 2.

The variables, instead, are represented by a range of values and their calculation is based on a study by NICHOLAS (2003); in particular, for identifying interest rates variable, we follow the approach proposed by PRICE (2011). Variables are functional to perform the Sensitivity Analysis, as shown in Table 3.

*Table 2* – Average cost per hectare of cultural operations.

| Cultivation Operations | € $ha^{-1}$ |
|---|---|
| Tillage | 206 |
| Harrowing | 103 |
| Transport and distribution of fertilizers | 160 |
| Planting out | 600 |
| Pest and disease control | 150 |
| Mechanical weed control between rows, 1st year | 40 |
| Mechanical weed control between rows, 3rd year | 120 |
| Chemical weed control between rows, 1st year | 60 |
| Chemical weed control between rows, 3rd year | 120 |
| Fertilization | 60 |
| Irrigation | 100 |
| Harvesting | 310 |
| Transport | 370 |
| Soil re-establishment | 510 |

### *3.2. Sensitivity Analysis*

Sensitivity analysis is a technique used to determine how different values of an independent variable will impact a particular dependent variable under a given set of assumptions. The technique is used within specific boundaries that will depend on one or more input variables. This analysis is a way to predict the outcome of a decision if a situation

[3] SCM is structured in 4 spreadsheets: 1. Constants-Variables; 2. Base case; 3. Low case; 4. High case. (Appendix: Tables I-II-III-IV).

*Table 3* – Variables (ranges of values tested).

| Factors tested | Values tested |
|---|---|
| Land property cost (€ $ha^{-1}$ $yr^{-1}$) | 0 - 200 - 600 |
| Average yield (odt $ha^{-1}$) | 9.28 - 10.44 - 11.60 |
| Interest rate (%) | 5% - 6% - 7% |
| Total cost of planting stock (€) | 2,400 - 5,000 - 8,400 |
| Output price (€ $odt^{-1}$) | 69.00 - 80.00 - 100.00 |

turns out to be different compared to the key prediction(s).

Sensitivity analysis is very useful when attempting to determine the impact the actual outcome of a particular variable will have, if it differs from what was previously assumed. In our case we have created a financial model (SCM), illustrated at §3.1, that value a black locust SRF plantation's flow (the dependent variable) given the different values of several independent variables (Table 3). These variables are listed in the SCM model (Appendix – Table I).

The total number of possible combinations of variables for sensitivity analysis is 1,458, a figure obtained by multiplying 3 interest rates by 9 total costs of planting stock, by 3 average yield values, by 6 land property costs values and by 3 possible output prices. This means that we can create a set of different scenarios, which include base case in the centre, and low case and high case at the extremes (Table 4).

For this reason we adopted three scenarios following the approach indicated by NICHOLAS (2003) and its conclusions. The economic analysis of the scenarios is presented in the following paragraphs.

3.2.1. Base case

Base case calculations are carried out on average values of variables regarding the following parameters:

– *land property cost* of € 200 per hectare, which derives from the product of:
  - cost per hectare of land: € 10,000;
  - interest rate (applied to the cost of land): 2%;
– *average yield*: 10.44 odt $ha^{-1}$;
– *interest rate* of 6%;
– *total cost of planting stock* of € 5,000, which derive from the product of:
  - planting stock unit cost: € 0.50;
  - planting stock density 10,000 (No. $ha^{-1}$);
– *output price*: € 80.00 $odt^{-1}$.

The flow, which is the difference between annual Vendible Gross Production (VGP)[4] and total costs per year is equal to 835.20 – 1,390.79 = -555.59 (see Appendix – Table II).

3.2.2. Low case

The most influential reductions in growing costs have been with these values of parameters:

– *land property cost* of € 0 per hectare, which derives from the product of:
  - cost per hectare of land: € 0;
  - interest rate (applied to the cost of land): 1%;
– *average yield*: 11.60 odt $ha^{-1}$;
– *interest rate* of 5%;
– *total cost of planting stock* of € 2,400, which derive from the product of:
  - planting stock unit cost: € 0.30;
  - planting stock density 8,000 (No. $ha^{-1}$);
– *output price*: € 100.00 $odt^{-1}$.

The Flow is equal to this calculation: 1,160.00 – 940.17 = 219.83 (see Appendix – Table III).

3.2.3. High case

The largest increase in growing costs derived from these values of parameters:

– *land property costs* of € 600, which derive from the product of:
  - cost per hectare of land: € 20,000;
  - interest rate (applied to the cost of land): 3%;
– *average yield*: 9.28 odt $ha^{-1}$;
– *interest rate* of 7%;
– *total cost of planting stock* of € 8,400, which derive from the product of:
  - planting stock unit cost: € 0.70;
  - planting stock density 12,000 (No. ha-1);
– *output price*: € 69.00 $odt^{-1}$.

The Flow is equal to this calculation: 640.32 – 2,135.08 = -1,494.76 (see Appendix – Table IV).

[4] The annual VGP is evaluated as the VGP average obtained at the end of each rotation cycle, over the 15 years.

*Table 4* – Low / Base / High case and ranges of values tested.

| *Factors tested* | Low case | Base case | High case | Values tested |
|---|---|---|---|---|
| Land property costs (€ $ha^{-1}$ $yr^{-1}$) | 0 | 200 | 600 | 0 - 200 - 600 |
| Average yield (odt $ha^{-1}$) | 11.60 | 10.44 | 9.28 | 9.28 - 10.44 - 11.60 |
| Interest rate (%) | 5% | 6% | 7% | 5% - 6% - 7% |
| Total cost of planting stock (€) | 2,400 | 5,000 | 8,400 | 2,400 - 5,000 - 8,400 |
| Output price (€ $odt^{-1}$) | 100.00 | 80.00 | 69.00 | 69.00 - 80.00 - 100.00 |

## 4. Economic Results

The model shows that the most influential constant values on costs are, as shown in Table 5:
– Planting out (21%);
– Soil re-establishment (18%);
– Transport (13%);
– Harvesting (11%);
– Tillage (7%).

As it is widely illustrated in §3.2.1, 3.2.2, 3.2.3 the variables that most influence, in different way, the flow are:
– average yield;
– output price;
– land property costs;
– total cost of planting stock;
– interest rate.

Sensitivity analysis has shown that increases in yield and price make considerable reductions in growing costs, compared to the base case. In fact, the difference between the flow of the low case and the flow of the base case is € 775.42. This means that revenues cover costs and allow earning a profit of € 219.83, as shown in Table 6.

*Table 5* – Cultivation operations.

| Cultivation Operations | Percentage |
|---|---|
| Tillage | 7% |
| Harrowing | 4% |
| Transport and distribution of fertilizers | 6% |
| Planting out | 21% |
| Pest and disease control | 5% |
| Mechanical weed control between rows | 6% |
| Chemical weed control between rows | 6% |
| Fertilization | 2% |
| Irrigation | 3% |
| Harvesting | 11% |
| Transport | 13% |
| Soil re-establishment | 18% |

At the same time, project management costs, such as land property costs, total cost of planting stock and interest rate, increase the cropping costs compared to the base case. The flow's difference between high case and base case is a negative flow of € 939.17, which is two times higher than the one of the base case (Table 6).

*Table 6* – Low / Base / High case Flow.

| | Flow (VGP-TOTAL COSTS) |
|---|---|
| Low case | *219.83* |
| Base case | *-555.59* |
| High case | *-1,494.76* |

## 5. Conclusions

The SRF still constitutes a marginal reality in the national agriculture system. This is unsurprising considering the lack of initiatives for widespread use of biomass on a large scale. If this gap is filled, SRF would then be able to promise certain remuneration to the producers.

It seems that two factors are key for SRF profitability: genetic material and cultivation techniques. In this respect, effort will be required in research and development, firstly, of more productive, resistant clones, as yield is one of the main factor for profitability; secondly for improving cultivation techniques and their costs. Both factors are currently in development at various farming operations. Only a better combination of the two factors above mentioned can achieve the best economic results for SRF farms.

That's why it is important to do an analysis showing how many factors are required before taking action, as well as addressing all of the positives of biomass energy use on a large scale.

These factors are, as regards the operations of cultivation:

- availability of fertile sites, from the pedologic and climate point of view, to obtain high production levels;
- putting in place the best cultivation techniques and management technologies available to minimize the cost of cultivation;
- presence of facilities for the use of the product in a radius of fewer than ten kilometers, to contain transport costs;
- availability of adequate land area suitable for SRF crops able to justify the establishment of infrastructures.

It is considered the mechanization of the harvesting phase of the product which involves considerable investments justifiable only in the presence of a large area to allow obvious economies of scale.

There are also many other factors which influence, in different way, the choice of a SRF and for these we need to use an economic analysis such as sensitivity analysis.

The sensitivity analysis is used to measure different scenarios in order to estimate what are the safety margins that a bioenergy manager has to consider and within which decisions can be made. Furthermore, through this methodology, it is possible to identify which are the most important drivers of value that needs to be focused once the investment has been done.

The analysis of the sensitivity of growing costs has shown, as noted by NICHOLAS (2003), that a bioenergy manager can identify a range of values to take decisions and make a significant reduction in the growing costs of the operation. In fact, on the growing side, improvements in yield and price provide substantial reductions in growing cost. Project management costs, such as land property costs, total cost of planting stock and interest rate can significantly increase the costs of the SRF crop.

As a final consideration, public subsidies cannot be left out as a factor. This is also confirmed by previous similar studies carried out in Italy (FACCIOTTO *et al.*, 2003; PANNACCI *et al.*, 2009; BACENETTI and FIALA, 2011). Public aid for SRF is quite controversial as it is sometimes considered inefficient if not wasteful. In fact, most traditional crops benefit from various (direct or indirect) types of public support. It should not be neglected to consider that SRF may be beneficial in environmental terms. In fact SRF cultivation requires less input use, both in energy and chemicals, compared to traditional agricultural crops and may produce positive effects in terms of biodiversity, soil quality, landscape appearance, water availability and quality, pollution of rivers and lakes and production of toxic emissions.

Ultimately, the issue of support of SRF is part of the more general problem of supporting agriculture. In point of fact, SRF permits choices in agricultural policy that will be increasingly directed towards the creation of an agricultural system promoting growth, multifunctional, and able to generate positive externalities, far beyond the growth area.

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## RIASSUNTO

### PIANTAGIONE FORESTALE A CICLO BREVE. UN'ANALISI DELLE PRATICHE COLTURALI ED UNA VALUTAZIONE ECONOMICA NELLA REGIONE LAZIO

L'articolo presenta dapprima un'analisi delle principali pratiche colturali di una piantagione di robinia (*Robinia pseudoacacia* L.), nella regione Lazio, che viene tagliata

ogni tre anni, per una rotazione complessiva di 15 anni; in secondo luogo, l'articolo presenta una valutazione economica, attraverso l'analisi di sensitività di un intervallo di valori rappresentati nello *Spreadsheet Costing Model* (SCM). L'obiettivo della valutazione è quello di aiutare *manager* e ricercatori nel campo della bioenergia su alcuni aspetti chiave della coltivazione in grado di incidere sulla redditività.

Il rapporto conclude che la SRF costituisce ancora una realtà marginale nel sistema agricolo nazionale. Ciò non sorprende se si considera la mancanza di iniziative – incluse quelle di ricerca e sperimentazione – volte alla diffusione delle piantagioni dedicate alla produzione di biomassa per energia su larga scala. Se tale carenza sarà colmata, la SRF sarà quindi in grado di promettere una certa remunerazione ai produttori.

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# APPENDIX

*Table I* – Constant-Variables.

| | *Constant values* | *Variables (range of values tested)* | | |
|---|---|---|---|---|
| *Production* | | | | |
| Yield increase, 1st year, $m^3\ ha^{-1}$ | | *8.00* | *10.00* | *12.00* |
| Yield increase, 4th-12th year, $m^3\ ha^{-1}$ | | *18.00* | *20.00* | *22.00* |
| Average yield increase, $m^3\ ha^{-1}\ yr^{-1}$ | | *16.00* | *18.00* | *20.00* |
| Biomass Basic density, odt $m^3$ | 0.58 | | | |
| Average yield increase, $odt^{-1}\ ha^{-1}$ | | *9.28* | *10.44* | *11.60* |
| Output price, € $odt^{-1}$ | | *69.00* | *80.00* | *100.00* |
| *Costs of cultivation operations* | | | | |
| Cost per hectare of land, € | | *0.00* | *10,000.00* | *20,000.00* |
| Interest rate | | *0.01* | *0.02* | *0.03* |
| Land property, € | | *0.00* | *200.00* | *600.00* |
| Tillage, € | 206.00 | | | |
| Harrowing, € | 103.00 | | | |
| Transport and Distribution of fertilizer, € | 160.00 | | | |
| Planting stock unit cost, € | | *0.30* | *0.50* | *0.70* |
| Planting stock density, No. $ha^{-1}$ | | *8,000.00* | *10,000.00* | *12,000.00* |
| Planting stock, € | | *2,400.00* | *5,000.00* | *8,400.00* |
| Planting out, € | 600.00 | | | |
| Pest and desease control, € | 150.00 | | | |
| Mechanical weed control between rows, 1st year, € | 40.00 | | | |
| Mechanical weed control between rows, 3rd year,€ | 120.00 | | | |
| Chemical weed control between rows, 1st year, € | 60.00 | | | |
| Chemical weed control between rows, 3rd year, € | 120.00 | | | |
| Fertilization, € | 60.00 | | | |
| Irrigation, € | 100.00 | | | |
| Harvesting, € | 310.00 | | | |
| Transport, € | 370.00 | | | |
| Restoration of soil, € | 510.00 | | | |
| Interest rate | | *0.05* | *0.06* | *0.07* |

*Table II* – Base case.

| | Values tested | rotation 1 | | | rotation 2 | | | rotation 3 | | | rotation 4 | | | rotation 5 | | | Average values |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | year 1 | year 2 | year 3 | year 1 | year 2 | year 3 | year 1 | year 2 | year 3 | year 1 | year 2 | year 3 | year 1 | year 2 | year 3 | |
| *Production* | | | | | | | | | | | | | | | | | |
| Average yield, $m^3 ha^{-1} yr^{-1}$ | *18.00* | *10.00* | *10.00* | *10.00* | *20.00* | *20.00* | *20.00* | *20.00* | *20.00* | *20.00* | *20.00* | *20.00* | *20.00* | *20.00* | *20.00* | *20.00* | *18.00* |
| Average yield, odt $ha^{-1} yr^{-1}$ | *10.44* | *5.80* | *5.80* | *5.80* | *11.60* | *11.60* | *11.60* | *11.60* | *11.60* | *11.60* | *11.60* | *11.60* | *11.60* | *11.60* | *11.60* | *11.60* | *10.44* |
| Output price, Euro $t^{-1}$ | *80.00* | | | *80.00* | | | *80.00* | | | *80.00* | | | *80.00* | | | *80.00* | |
| Vendible Gross Production (VGP), € | 12,528.00 | | | 1,392.00 | | | 2,784.00 | | | 2,784.00 | | | 2,784.00 | | | 2,784.00 | 835.20 |
| *Costs and operation costs* | | | | | | | | | | | | | | | | | |
| Land property, € | *200.00* | *200.00* | *200.00* | *200.00* | *200.00* | *200.00* | *200.00* | *200.00* | *200.00* | *200.00* | *200.00* | *200.00* | *200.00* | *200.00* | *200.00* | *200.00* | *200.00* |
| Tillage, € | 206.00 | 206.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | *13.73* |
| Harrowing, € | 103.00 | 103.00 | 0.00 | 0.00 | 103.00 | 0.00 | 0.00 | 103.00 | 0.00 | 0.00 | 103.00 | 0.00 | 0.00 | 103.00 | 0.00 | 0.00 | *34.33* |
| Transport and distribution of fertilizer, € | 160.00 | 160.00 | 0.00 | 0.00 | 160.00 | 0.00 | 0.00 | 160.00 | 0.00 | 0.00 | 160.00 | 0.00 | 0.00 | 160.00 | 0.00 | 0.00 | *53.33* |
| Planting stock, € | *5,000.00* | *1,250.00* | *0.00* | *0.00* | *1,250.00* | *0.00* | *0.00* | *1,250.00* | *0.00* | *0.00* | *1,250.00* | *0.00* | *0.00* | *1,250.00* | *0.00* | *0.00* | *416.67* |
| Planting out operation, € | 600.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | *50.00* |
| Pest and desease control, € | 150.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | *50.00* |
| Mechanical weed control between rows, € | 160.00 | 40.00 | 0.00 | 120.00 | 40.00 | 0.00 | 120.00 | 40.00 | 0.00 | 120.00 | 40.00 | 0.00 | 120.00 | 40.00 | 0.00 | 120.00 | *53.33* |
| Chemical weed control between rows, € | 180.00 | 60.00 | 0.00 | 120.00 | 60.00 | 0.00 | 120.00 | 60.00 | 0.00 | 120.00 | 60.00 | 0.00 | 120.00 | 60.00 | 0.00 | 120.00 | *60.00* |
| Fertilization, € | 60.00 | 60.00 | 0.00 | 0.00 | 60.00 | 0.00 | 0.00 | 60.00 | 0.00 | 0.00 | 60.00 | 0.00 | 0.00 | 60.00 | 0.00 | 0.00 | *20.00* |
| Irrigation, € | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | *100.00* |
| Harvesting, € | 310.00 | 0.00 | 0.00 | 310.00 | 0.00 | 0.00 | 310.00 | 0.00 | 0.00 | 310.00 | 0.00 | 0.00 | 310.00 | 0.00 | 0.00 | 310.00 | *103.33* |
| Transport, € | 370.00 | 0.00 | 0.00 | 370.00 | 0.00 | 0.00 | 370.00 | 0.00 | 0.00 | 370.00 | 0.00 | 0.00 | 370.00 | 0.00 | 0.00 | 370.00 | *123.33* |
| Soil re-establishment, € | 510.00 | | | | | | | | | | | | | | | 510.00 | *34.00* |
| Total costs of cultivation operations, € | 1,9681.00 | 2,329.00 | 450.00 | 1,220.00 | 2,123.00 | 450.00 | 1,220.00 | 2,123.00 | 450.00 | 1,220.00 | 2,123.00 | 450.00 | 1,220.00 | 2,123.00 | 450.00 | 1,730.00 | 1,312.07 |
| Interest, € | *-1,180.86* | *-139.74* | *-27.00* | *-73.20* | *-127.38* | *-27.00* | *-73.20* | *-127.38* | *-27.00* | *-73.20* | *-127.38* | *-27.00* | *-73.20* | *-127.38* | *-27.00* | *-103.80* | *-78.72* |
| Total costs, € | 2,0861.86 | 2,468.74 | 477.00 | 1,293.20 | 2,250.38 | 477.00 | 1,293.20 | 2,250.38 | 477.00 | 1,293.20 | 2,250.38 | 477.00 | 1,293.20 | 2,250.38 | 477.00 | 1,833.80 | 1,390.79 |
| | | | | | | | | | | | | | | | | | |
| Flow (VGP-Total costs), € | -8,333.86 | -1,076.74 | 915.00 | 98.80 | -858.38 | 915.00 | 98.80 | -858.38 | 915.00 | 98.80 | -858.38 | 915.00 | 98.80 | -858.38 | 915.00 | -441.80 | -555.59 |

*Table III* – Low case.

| | Values tested | rotation 1 | | | rotation 2 | | | rotation 3 | | | rotation 4 | | | rotation 5 | | | Average values |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | year 1 | year 2 | year 3 | year 1 | year 2 | year 3 | year 1 | year 2 | year 3 | year 1 | year 2 | year 3 | year 1 | year 2 | year 3 | |
| *Production* | | | | | | | | | | | | | | | | | |
| Average yield, $m^3 ha^{-1} yr^{-1}$ | *16.00* | *8.00* | *8.00* | *8.00* | *18.00* | *18.00* | *18.00* | *18.00* | *18.00* | *18.00* | *18.00* | *18.00* | *18.00* | *18.00* | *18.00* | *18.00* | *16.00* |
| Average yield, odt $ha^{-1} yr^{-1}$ | *9.28* | *4.64* | *4.64* | *4.64* | *10.44* | *10.44* | *10.44* | *10.44* | *10.44* | *10.44* | *10.44* | *10.44* | *10.44* | *10.44* | *10.44* | *10.44* | *9.28* |
| Output price, Euro $t^{-1}$ | *69.00* | | | *69.00* | | | *69.00* | | | *69.00* | | | *69.00* | | | *69.00* | |
| Vendible Gross Production (VGP), € | 9,604.80 | | | 960.48 | | | 2,161.08 | | | 2,161.08 | | | 2,161.08 | | | 2,161.08 | 640.32 |
| | | | | | | | | | | | | | | | | | |
| *Costs and operation costs* | | | | | | | | | | | | | | | | | |
| Land property, € | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* |
| Tillage, € | 206.00 | 206.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | *13.73* |
| Harrowing, € | 103.00 | 103.00 | 0.00 | 0.00 | 103.00 | 0.00 | 0.00 | 103.00 | 0.00 | 0.00 | 103.00 | 0.00 | 0.00 | 103.00 | 0.00 | 0.00 | *34.33* |
| Transport and distribution of fertilizer, € | 160.00 | 160.00 | 0.00 | 0.00 | 160.00 | 0.00 | 0.00 | 160.00 | 0.00 | 0.00 | 160.00 | 0.00 | 0.00 | 160.00 | 0.00 | 0.00 | *53.33* |
| Planting stock, € | *8,400.00* | *2,100.00* | *0.00* | *0.00* | *2,100.00* | *0.00* | *0.00* | *2,100.00* | *0.00* | *0.00* | *2,100.00* | *0.00* | *0.00* | *2,100.00* | *0.00* | *0.00* | *700.00* |
| Planting out operation, € | 600.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | *50.00* |
| Pest and desease control, € | 150.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | *50.00* |
| Mechanical weed control between rows, € | 160.00 | 40.00 | 0.00 | 120.00 | 40.00 | 0.00 | 120.00 | 40.00 | 0.00 | 120.00 | 40.00 | 0.00 | 120.00 | 40.00 | 0.00 | 120.00 | *53.33* |
| Chemical weed control between rows, € | 180.00 | 60.00 | 0.00 | 120.00 | 60.00 | 0.00 | 120.00 | 60.00 | 0.00 | 120.00 | 60.00 | 0.00 | 120.00 | 60.00 | 0.00 | 120.00 | *60.00* |
| Fertilization, € | 60.00 | 60.00 | 0.00 | 0.00 | 60.00 | 0.00 | 0.00 | 60.00 | 0.00 | 0.00 | 60.00 | 0.00 | 0.00 | 60.00 | 0.00 | 0.00 | *20.00* |
| Irrigation, € | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | *100.00* |
| Harvesting, € | 310.00 | 0.00 | 0.00 | 310.00 | 0.00 | 0.00 | 310.00 | 0.00 | 0.00 | 310.00 | 0.00 | 0.00 | 310.00 | 0.00 | 0.00 | 310.00 | *103.33* |
| Transport, € | 370.00 | 0.00 | 0.00 | 370.00 | 0.00 | 0.00 | 370.00 | 0.00 | 0.00 | 370.00 | 0.00 | 0.00 | 370.00 | 0.00 | 0.00 | 370.00 | *123.33* |
| Soil re-establishment, € | 510.00 | | | | | | | | | | | | | | | 510.00 | *34.00* |
| Total costs of cultivation operations, € | 2,9931.00 | 3,579.00 | 850.00 | 1,620.00 | 3,373.00 | 850.00 | 1,620.00 | 3,373.00 | 850.00 | 1,620.00 | 3,373.00 | 850.00 | 1,620.00 | 3,373.00 | 850.00 | 2,130.00 | 1,995.40 |
| Interest, € | *-2,095.17* | *-250.53* | *-59.50* | *-113.40* | *-236.11* | *-59.50* | *-113.40* | *-236.11* | *-59.50* | *-113.40* | *-236.11* | *-59.50* | *-113.40* | *-236.11* | *-59.50* | *-149.10* | *-139.68* |
| Total costs, € | 32,026.17 | 3,829.53 | 909.50 | 1,733.40 | 3,609.11 | 909.50 | 1,733.40 | 3,609.11 | 909.50 | 1,733.40 | 3,609.11 | 909.50 | 1,733.40 | 3,609.11 | 909.50 | 2,279.10 | 2,135.08 |
| | | | | | | | | | | | | | | | | | |
| Flow (VGP-Total costs), € | -22,421.37 | -2,869.05 | 50.98 | -772.92 | -2,648.63 | 50.98 | -772.92 | -2,648.63 | 50.98 | -772.92 | -2,648.63 | 50.98 | -772.92 | -2,648.63 | 50.98 | -1,318.62 | -1,494.76 |

*Table IV* – High case.

| | Values tested | rotation 1 | | | rotation 2 | | | rotation 3 | | | rotation 4 | | | rotation 5 | | | Average values |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | year 1 | year 2 | year 3 | year 1 | year 2 | year 3 | year 1 | year 2 | year 3 | year 1 | year 2 | year 3 | year 1 | year 2 | year 3 | |
| *Production* | | | | | | | | | | | | | | | | | |
| Average yield, $m^3 ha^{-1} yr^{-1}$ | *16.00* | *8.00* | *8.00* | *8.00* | *18.00* | *18.00* | *18.00* | *18.00* | *18.00* | *18.00* | *18.00* | *18.00* | *18.00* | *18.00* | *18.00* | *18.00* | *16.00* |
| Average yield, odt $ha^{-1} yr^{-1}$ | *9.28* | *4.64* | *4.64* | *4.64* | *10.44* | *10.44* | *10.44* | *10.44* | *10.44* | *10.44* | *10.44* | *10.44* | *10.44* | *10.44* | *10.44* | *10.44* | *9.28* |
| Output price, Euro $t^{-1}$ | *69.00* | | | *69.00* | | | *69.00* | | | *69.00* | | | *69.00* | | | *69.00* | |
| Vendible Gross Production (VGP), € | 9,604.80 | | | 960.48 | | | 2,161.08 | | | 2,161.08 | | | 2,161.08 | | | 2,161.08 | 640.32 |
| | | | | | | | | | | | | | | | | | |
| *Costs and operation costs* | | | | | | | | | | | | | | | | | |
| Land property, € | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* | *600.00* |
| Tillage, € | 206.00 | 206.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | *13.73* |
| Harrowing, € | 103.00 | 103.00 | 0.00 | 0.00 | 103.00 | 0.00 | 0.00 | 103.00 | 0.00 | 0.00 | 103.00 | 0.00 | 0.00 | 103.00 | 0.00 | 0.00 | *34.33* |
| Transport and distribution of fertilizer, € | 160.00 | 160.00 | 0.00 | 0.00 | 160.00 | 0.00 | 0.00 | 160.00 | 0.00 | 0.00 | 160.00 | 0.00 | 0.00 | 160.00 | 0.00 | 0.00 | *53.33* |
| Planting stock, € | *8,400.00* | *2,100.00* | *0.00* | *0.00* | *2,100.00* | *0.00* | *0.00* | *2,100.00* | *0.00* | *0.00* | *2,100.00* | *0.00* | *0.00* | *2,100.00* | *0.00* | *0.00* | *700.00* |
| Planting out operation, € | 600.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | *50.00* |
| Pest and desease control, € | 150.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | 0.00 | 150.00 | 0.00 | *50.00* |
| Mechanical weed control between rows, € | 160.00 | 40.00 | 0.00 | 120.00 | 40.00 | 0.00 | 120.00 | 40.00 | 0.00 | 120.00 | 40.00 | 0.00 | 120.00 | 40.00 | 0.00 | 120.00 | *53.33* |
| Chemical weed control between rows, € | 180.00 | 60.00 | 0.00 | 120.00 | 60.00 | 0.00 | 120.00 | 60.00 | 0.00 | 120.00 | 60.00 | 0.00 | 120.00 | 60.00 | 0.00 | 120.00 | *60.00* |
| Fertilization, € | 60.00 | 60.00 | 0.00 | 0.00 | 60.00 | 0.00 | 0.00 | 60.00 | 0.00 | 0.00 | 60.00 | 0.00 | 0.00 | 60.00 | 0.00 | 0.00 | *20.00* |
| Irrigation, € | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | *100.00* |
| Harvesting, € | 310.00 | 0.00 | 0.00 | 310.00 | 0.00 | 0.00 | 310.00 | 0.00 | 0.00 | 310.00 | 0.00 | 0.00 | 310.00 | 0.00 | 0.00 | 310.00 | *103.33* |
| Transport, € | 370.00 | 0.00 | 0.00 | 370.00 | 0.00 | 0.00 | 370.00 | 0.00 | 0.00 | 370.00 | 0.00 | 0.00 | 370.00 | 0.00 | 0.00 | 370.00 | *123.33* |
| Soil re-establishment, € | 510.00 | | | | | | | | | | | | | | | 510.00 | *34.00* |
| Total costs of cultivation operations, € | 2,9931.00 | 3,579.00 | 850.00 | 1,620.00 | 3,373.00 | 850.00 | 1,620.00 | 3,373.00 | 850.00 | 1,620.00 | 3,373.00 | 850.00 | 1,620.00 | 3,373.00 | 850.00 | 2,130.00 | 1,995.40 |
| Interest, € | *-2,095.17* | *-250.53* | *-59.50* | *-113.40* | *-236.11* | *-59.50* | *-113.40* | *-236.11* | *-59.50* | *-113.40* | *-236.11* | *-59.50* | *-113.40* | *-236.11* | *-59.50* | *-149.10* | *-139.68* |
| Total costs, € | 32,026.17 | 3,829.53 | 909.50 | 1,733.40 | 3,609.11 | 909.50 | 1,733.40 | 3,609.11 | 909.50 | 1,733.40 | 3,609.11 | 909.50 | 1,733.40 | 3,609.11 | 909.50 | 2,279.10 | 2,135.08 |
| | | | | | | | | | | | | | | | | | |
| Flow (VGP-Total costs), € | -22,421.37 | -2,869.05 | 50.98 | -772.92 | -2,648.63 | 50.98 | -772.92 | -2,648.63 | 50.98 | -772.92 | -2,648.63 | 50.98 | -772.92 | -2,648.63 | 50.98 | -1,318.62 | -1,494.76 |

Bianca