TECHNOLOGICAL OPPORTUNITIES SURVEY OF FOREST SHORT ROTATION PLANTATIONS IN BULGARIA FOR ENERGY BIOMASS PRODUCTION* PART 2: TECHNOLOGY STAGES OF CREATION AND CULTIVATION OF WOOD BIOMASS PLANTATIONS

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ABSTRACT

A study on the technologies for creating and growing SRC plantations for the production of biomass for energy purposes has been conducted in the present report. An analysis of the main steps in the technological process has been made. Recommendations are made to the Bulgarian farmers on the necessary techniques for incorporating the crops and the use of appropriate machinery for site preparation, planting and growing of crops.

Key words: short rotation crops, mechanized technologies

INTRODUCTION

According to BIOPROS project, besides conventional forestry, a huge potential for solid biomass production is expected to come from high yielding, coppiceable tree species such as willows (Salix spp.) and poplars (Populus spp.), cultivated in plantations with dense stands and relatively short rotation harvesting cycles of 3 – 5 years. In order to meet the White Paper objectives it is estimated that about 4,5 % of the EU total agricultural area (6,3 million ha) must be cultivated with such dedicated energy crops, but competition with food and fodder production must seriously be taken into account.

The new support schemes include the possibility of using mandatory set-aside land for energy crop production, including SRC crops. Thus, in combination with an increasing market for woody biomass for district heating schemes and co-combustion in power plants, the current CAP strengthens the position of SRP for biomass production and creates new sources of income for European farmers in a growing market for bioenergy (BIOPROS).

1. PLANTATION SITE SELECTION

The proper site selection is essential. In comparison to annual crops, the decision about establishing new SRC will affect land management and the economics of a farm for many years, given an expected life span of SRC in European conditions of around 25 – 30 years against costs which are largely concentrated in the plantation's first growing season. Therefore any mistake made in terms of selecting the appropriate site has an economic impact which is almost impossible to correct.

Climatic conditions: It is generally accepted that genus Salix which can be considered as the best option for SRC for regions in Central and Northern Europe is very tolerant to a wide range of climatic and soil factors. Poplars seem to have different climatic and water demands, growing better in warmer climates and having lower water requirements. Poplar is far more susceptible than willow to frost, therefore its low winter hardiness limits its climatic range. Autumn and spring frosts can cause a lot of damage in poplar plantations. Climatic conditions therefore seem to limit the location of poplar plantations more than soil factors (BIOPROS).

Water availability: The willow is characterized by a very high evapotranspiration rate and by its ability to withstand seasonal flooding. On the other hand Salix roots cannot survive long periods of anaerobic conditions and hence permanently flooded sites cannot be taken into consideration as a site for SRC. Willow is able to give a substantially high biomass yield when precipitation is higher than 575 – 600 mm/m^2 annually. If waste water irrigation is an option, then dryer sites may be selected because low rainfall will be compensated for, provided that a good supply of essential nutrients is forthcoming (BIOPROS).

Groundwater: It is generally accepted that groundwater tables for maintaining high productivity of biomass cannot be lower than 120 – 150 cm. Therefore light sandy soils should be excluded as an appropriate SRC site. To some extent irrigation with wastewater facilitated the introduction of SRC on sites where the ground water table is deeper (BIOPROS).

Soils: Organic and peaty soils must be excluded as an appropriate site for SRP given that heavy machinery cannot operate under such conditions. The natural process taking place in peaty soils often leads to anaerobic conditions which are very harmful for the developing roots of active growing plants. The ideal site for SRC establishment represents mineral rich soils abundant in nutrients and organic matter, and flat land given that selecting fields, which can be harvested economically is of critical importance. The best soils are loamy sand, light loamy clays i.e. soils of high agricultural quality with good aeration and moisture retention. Due to the fact that these soils are also ideal for food and fodder crop production means that compromises will have to be made.

Infrastructure and vehicle access: Existing infrastructure is another factor which should be taken into account when selecting an SRC site, as in most countries profitable SRC cultivation requires the introduction of heavy machinery. This includes a road network enabling proper logistics throughout the whole SRC growth cycle starting from pre-planting site preparation, the delivery of cuttings, infrastructure for sewage sludge transportation, pipeline transportation of wastewater during the lifespan of the plantation, and ending with the harvesting and transportation of the harvested biomass. It is important not to have high tension electricity wires hanging lower than 6m above the ground surface, as poplar and willow plants when harvested in three to four year cycles can grow up to 8m (BIOPROS). Consequently, spatial distribution of SRP will affect the economics of the whole system.

Distance to end user**:** There are recommendations concerning the maximum distance between the SRC site and the end-user of biomass. This depends on many factors but among them the capacity of transportation units and the existing road system, as well as fuel price are crucial. A maximum distance of 40 – 80 km between the end biomass user and the SRP is generally recommended (Cornier 2006). Close proximity to a heat or power plant interested in purchasing biomass fuel would represent a very positive advantage for SRP establishment.

2. CHOICE OF WOOD SPECIES AND PLANTING MATERIAL

The choice of a tree species is related to the knowledge of some basic biological requirements of the tree species and the characteristics of the cultivation process of the crops. Our country falls into a climatic zone that is suitable for growing of fast-growing species such as poplar, willow, aspen, alder, white acacia and others. From an economic point of view the most important factor when choosing plant material is the potential crop yield. However, one must also assess the microclimate of the proposed plantation area (soil moisture content, probability of late spring frosts etc.) before looking for suitable planting material from cuttings producers. When choosing suitable material, licensed plant nurseries should be the preferred source, as their planting material is a product of extensive breeding research programs and therefore of predictable characteristics and good quality. In general poplars are more drought resistant than willows, but suffer more often from frosts. Also different willow/poplar clones may have different frost, drought and disease resistance characteristics/tolerances. This is very important to bear in mind when choosing to establish a SRP with poplars or willows. The planting investment required is significant and therefore it is necessary that most of the plants survive not only during the first year but during subsequent harvesting cycles, to give a satisfactory wood yield for several years. Sometimes profit margins from biomass can be increased by energy crop subsidies available for particular species in some countries. Hence it is useful to be familiar with not only the availability, but the terms and conditions of such subsidy programs before SRP establishment. On the other hand, subsidy policy may change through time and should not be the main reason for entering into the bioenergy industry.

One option to reduce the risk of high plant mortality during the plantation lifespan is to use appropriate planting material for plantation establishment. The breeding programs of both willows and poplars continuously provide new clones and varieties with higher yield characteristics and improved tolerance to various risk factors. Besides productivity, disease resistance and frost tolerance the criteria for planting material choice from particular genus should also include clone resprouting capacity after coppicing and typical crown shape. Tree-shaped clones have a higher wood/bark ratio and therefore a higher energetic value. On the other hand, large shoot diameters can cause a problem during harvesting for some specific harvesters if the plantation is planned to coppice less often.

Willow (*Salix sp.*): Willow is grown mainly in the European Northern parts, Sweden, UK, Finland, Denmark, Ireland and the Netherlands produce willow. It is estimated that current net yield in Sweden is 8-18 odt/ha/year, in UK annual yields are between 8 and 20 odt/ha/year, Denmark is the mean yield 10 – 18 odt/ha/year, in Ireland about 11 odt/ha/year and Slovakia between 10 and 12 odt/ha, where odt is oven dry mass chips (Lieskovský 2011).

Strengths**:** The establishment is relatively easy and cheap; -Willow production is environmentally friendly.

Weakness: The crop water requirement is high, and often water availability is the factor for the production; - The long crop rotation, the lack of long-term legislation and the risk of increased pest problems are among the barriers; - The introduction of new technical development to farmer is a major bottleneck.

Poplar *(Populus sp.)*: Poplar can be grown in warmer climates than willow. In some countries like the UK, Ireland, Belgium, Austria and Germany both species are grown. Poplar has been investigated in central European countries and the UK since long. Annual yields expected mean 15-20 odt/ha. In Italy 18 – 26 odt/ha/year have been obtained under irrigation in small research plots, in France annual yields of 11 – 15 odt/ha are estimated under commercial conditions (van Oosten 2004).

Strengths**:** Compared to willow poplar is more resistant to pests and disease.

Weakness: High establishing costs; Poplar did not tolerate high soil contents of heavy metals; Wild animal may however cause problems; Demand for irrigation

Criteria for planting material choice:

1) Species and clones suitable for local site conditions;
2) Productivity and clone re-sprouting after coppicing;
3) Disease resistance and frost tolerance;
4) Typical crown shape;
5) Material from licensed nurseries.

Farmers are sometimes encouraged to plant 4 – 8 clones into separate rows/blocks of a plantation in order to decrease the infection risks.

3. SITE PREPARATION

Essentially all SRC operations employ conventional agricultural equipment and methods when preparing areas for planting. SRC is a perennial crop and once it is established it will last for at least 20 years: the adequate soil conditions may have a great influence in the success of the plantation (Ledin and Willebrand 1995). Because of this, plowing, cultivation and land preparation are very important prior to plantation. Tree roots have a much deeper development than the annual herbaceous species and are much more effective in exploring the soil layers for water and nutrients, but in agricultural fields, repeated plowing at normal depth (30 – 50 cm) tend to form a hard pan. Which is not a limit for normal crops, being deeper than their root system, but is an impediment for trees development. A deep plowing (100 cm) is recommended in order to create the optimal conditions of root soil penetration. This operation allows the complete development of trees roots and enhances the soil water reservoir (Facciotto 2005). Because of its high cost, this operation can be substituted by crossed ripping (100 cm) followed by a low depth plowing (30 cm). The latter option has further advantage of not uptaking material from the deep layers, rich in nutrients, where they are available for SRC roots but not for weeds. After the main operation the site has to be carefully cultivated in order to provide soft bedding for the following operation of establishment.

Site preparation on the flood prone areas may include crossed two discings with a disc plows, pulled by crawler tractors, and ripping. On diked floodplain sites along the rivers, site preparation may includes ditching, installing drain tile on the wetter spots, four to five plowing or discing passes, mechanical spading and rototilling.

4. PLANTING

According to the site characteristics, it is important to identify the most suitable clone or clones for the plantation. The choice of the adequate clone matching the site conditions is basic for successful plantations: by limiting the stress due to abiotic factors it will improve the productivity and the resistance to pest and diseases. There are many possible constraints that may heavily affect the productivity or even the survival of the trees:

- late or early frosts;
- periodic flooding or very high water table;
- poor or excessive drainage;
- extremely clay or sandy soil;
- extreme soil pH or high content of toxic elements such as heavy metals. SRC of willow can be used in a phytoremediation purpose, but in this case specific clones have to be used, and productivity will be anyway reduced by high heavy metal concentrations.

Many poplar and willow clones are available, specifically selected for SRC cultivation and for providing good performance of growth under different environmental conditions (Mead 2005). The availability of appropriate clones in local nurseries should be the first step when planning a SRC plantation. Willow and poplar SRC are generally established using woody cuttings, which has many advantages over rooted seedlings:

- production, based on coppice nurseries, is easier;
- storage can be easily performed for many weeks in dark fridge rooms at a temperature of 2 (± 1) ºC;
- planting can be fully mechanized.

Cuttings are produced in nurseries sectioning whips and poles with shears and generally have a length of 20 – 25 cm (Kopp et al. 2001) and a minimum diameter of 5 mm. The planting should be done as early in the spring as possible and cuttings should be planted in upright position.

Because of the high number of plants per hectares, establishment of SRC plantations has to be realized with a high grade of mechanization, and even so this operation can represent over 30 % of total costs (Rosenqvist and Dawson 2005), mostly due to the cost of cuttings, hence is very important to apply techniques that may reduce its impact on the overall cost. Research has been devoted to improve planting operations with specific machinery and many prototypes have been developed, particularly in Northern Europe

- Track cutting planter „Rotor“, commonly used in Italy and specific for poplar cuttings in nursery establishment; this machine uses 25 – 20 cm cuttings, two planters can be coupled to a single tractor allowing to plant in one passage two rows (Figure 1);

Figure 1: Track cutting planter „Rotor“ (two planters, coupled together on the same tractor)

- Step Planter „Salix Maskiner AB“ developed specifically for willow short rotation coppice; this machine uses 1,2 – 1,8 m long whips (sectioning them in 20 – 25 cm cuttings during the planting operation) for planting up to 4 rows of cuttings in one operation (Figure 2);

Figure 2: Step Planter (the platform can be used by four operators at the same time)

- Forest transplanter „Quick-wood“, which can plant both cuttings and rooted tree seedlings performing the plantation on a single row;
- Pliers transplanter „Berto“, also able to handle cuttings and rooted material and planting a single row.

All machines plant the cuttings perpendicularly into the soil and are fed manually by operators. The Step Planter plants 6300 cutting per hour. This result is confirmed by Heller (2003) who estimates to plant one hectare (15300 cuttings) in about 2,5 hours. The Step Planter is convenient also because the used planting materials are whips, cheaper than cuttings. None the less, in Balsari's analysis (2002) the cost per planted cutting of this machine is lower compared with Berto and Rotor only if more than 6 ha per year are planted.

5. PLANTING LAYOUT AND DENSITY

Very high densities are proven to be more productive, but because of the increasing planting cost at denser spacing, in Swedish Willow plantations recommended densities vary between 10000 and 20000 cuttings per hectare, harvested on a three or four year cycle (Ledin and Willebrand 1995). Planting design is generally in single row or double row (Figure 3).

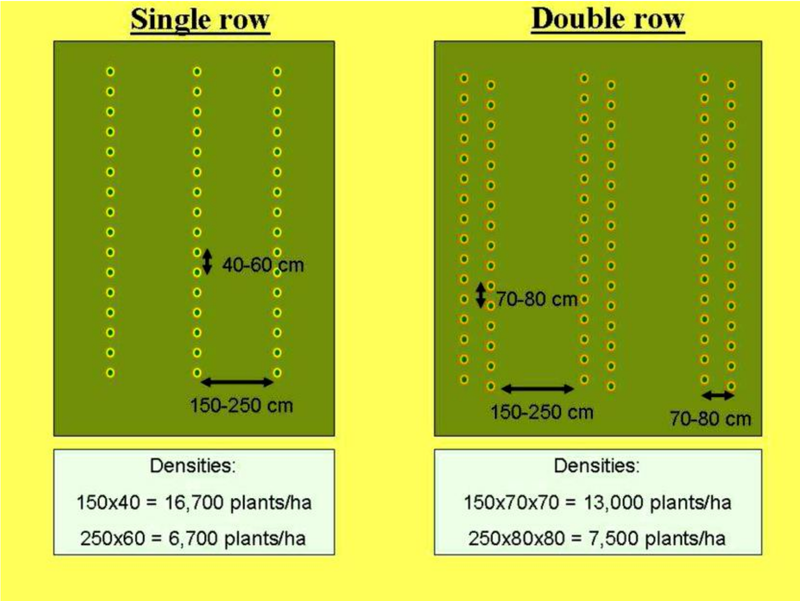

Figure 3: Layout of plantation – single and double row

The double row design is commonly used in willow, and it is meant to optimize the management of the field and particularly to enhance efficient harvest, while single row facilitates weeds control and other management operations (Facciotto 2005). However, care should be given when longer harvest cycles are used: an excessive density of big trees could obstacle the harvester. In the double row design, a spacing of at least 150 cm between each pair of rows, is desirable in order to allow the harvester to use wide tires (Hartsough and Spinelli 2002). Single rows are generally used in Italy for poplar SRC because of the high rate of growth: even with short harvest cycles (one or two years), the trees diameter and height can be excessive for the harvester if planted as a double row.

Generally, field shape follows terrain patterns or farm boundaries. Even if these constraining factors can hardly be changed, the efforts should be made to lay-out the fields in the most rational way for machinery movement. The theoretical field is rectangular in shape, with cross-roads 150 m apart. These cross roads allow biomass loading shuttle units to break out of the row and drive to the landing (Figure 4). The cross-roads should be wide enough to allow the shuttle tractor and trailer to exit and enter the field without damaging the last stools of the rows. This means a width of 6 to 8 m. For traffic only, a width of 8 m is sufficient, but if the area is used for biomass storage or re-loading into containers, a larger space is required.

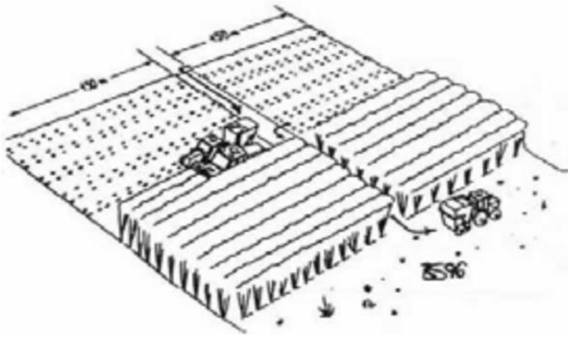

Figure 4: The ideal field layout with frequent cross roads

Adequate headlands must be provided. Insufficient turning space is the most frequent reason for poor harvesting performance: it imposes complicated maneuvering, which results in soil rutting and decreased productivity. Shuttle traffic will cross the area, and the harvester will turn at headlands. If the product is stored at the headland, one will consider the storage time and the eventual passage needs of other users or of the same user for other tasks.

Short rows should be avoided. They impose an intolerable increase of turning time, and a comparative reduction of productive time (Figure 5). Sometimes, rows are so short that turning would take longer than reversing to the starting position. Rational row length varies between 100 and 150 m. Given the average yield of SRC crops, most "direct-one-stage" harvesters can complete a load within this distance. When planting longer fields, cross-roads should be laid out with an interval of 150 m.

Figure 5: Short rows reduce harvester productivity demanding more time for turning

The rows should form a right angle to the headlands and the cross-roads, in order to allow the machines to enter the row from both directions, so as to facilitate harvesting up and down the rows. If the field is skewed with respect to the headland, rows should bend over the last 10 or 20 m to enter the headland at a right angle (Figure 6).

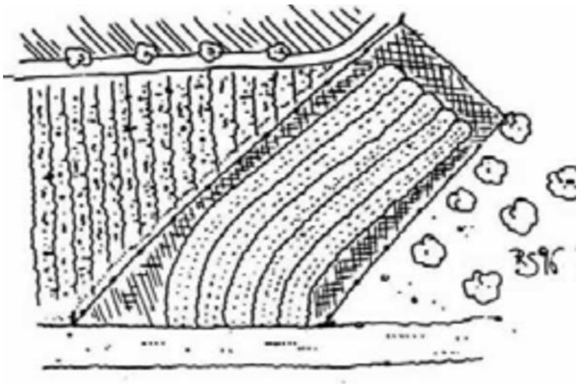

Figure 6: The tree rows should bend to enter the road/ headland perpendicularly

Row spacing is crucial to machine productivity. Even if most harvesters can technically handle both situations, using a double-row harvester on single rows means curtailing its productivity. Therefore, at the time of establishment, one should already gather information on the type of harvester which is likely to be available in a 3 – 4 years time. Very short rotations require a short spacing along the rows, in the order of 45 – 80 cm. Of course, much depends on tree development. If the stems are expected to reach a considerable height before harvesting, then spacing must be increased - especially if they are harvested with a cut and chip machine. Most such machines need to lay the tree horizontal after cutting, in order to feed it to the comminuting device. If trees are taller than 5-6 m and/or thick and branchy, a narrow spacing increases the risk of them getting stuck to the trees ahead, still to be cut resulting in machine blockage.

6 GROWING

6.1. Weed control

As pioneer species, both willow and poplar have a low competitive ability. Intensive site preparation and weed control (Figure 7) are essential prior to planting and during the establishment phase (Mitchell et al. 1999). During the first year poplars and willow enrooted cuttings are intolerant to weed competition, which can lead the plantation to fail. Swedish experience show, that poor or unsuccessful weed management of SRC plantations is the major reason that took farmers to convert SRC plantations to other crops.

a *b*

Figure 7: Weed control with line cultivator: *a* – in the planting year; *b* – in the second year

Post-planting residual herbicide can be applied to prevent germination of annual weeds for 3 – 6 months after planting, allowing the cuttings to establish canopy cover and facilitate natural suppression. Occasionally, despite careful preparation, weeds may become a problem within the crop. Both, manual and chemical remedial treatments are expensive and involve the risk of damaging the crop. Contact herbicide mix can be applied using a low-pressure spray to ensure minimum contact with crop foliage.

Following harvest, there is normally a degree of weed seed germination which can rapidly become problematic if not controlled. Post-harvest treatments are generally safer, the most effective being an overall spray of contact and residual herbicide applied in early spring before the coppice resprouts (Mitchell 1999). Once the plantation is established, the sprouts can easily overgrow the weeds, even after coppicing. Then a normal mechanical control should be done only between the plantation rows.

6.2. FERTILIZATION

Nutrient removal by biomass harvest (total nutrient content of harvested plant material) and its potential consequences on future nutrient cycling and productivity is a well known problem (Berthelot et al. 2000). Willow and poplar trees have a low nutrient requirement because the nutrient-rich leaves restitute to the ground most of the up taken elements. Nevertheless, due to of the high biomass production, SRC is very likely to have a higher nutrient demand if compared to any tree cultivation and quite similar to field crops.

In spite of the amount of nutrients extracted with the biomass harvest from the field, many studies show that additional supply of nutrients to SRC plantations growing on former arable land generally does not enhance tree growth significantly (Makeschin 1999). This may be due to the deep root system of woody crops compared to herbaceous ones, thus when cultivated on former crop land SRC may be able to reach nutrient accumulated in the deep layers with previous agricultural inputs.

Fertilization should only restitute to the field the nutrients removed with the harvested biomass. A low nutrient input will also produce environmental benefits in terms of water and soil contamination by leachate nutrients compared to herbaceous field crops. Different soil condition will anyway require different management: where clay soils are probably most prone to offer high reservoirs of nutrients in deep layers, sandy soils are very likely to require a stronger use of fertilizers; in fact on such substrates the response of willow to nitrogen fertilization is stronger (BIOPROS). Over a period of 6 years Scholz (2002) observed a 6% production decline when *N* was reduced from 150 to 75 kg/ha/y, while no fertilization caused a decrease of 20-40%. Poplar yields no significant decrease of lack of nitrogen fertilization.

In any soil conditions fertilization at establishment year is to be avoided: cuttings are unable to take advantage of nutrients available during the first year because of the poor root developments, thus weeds would be the most favored by an early fertilization. It is better postponed to the second year when the woody crops have developed a better root system and a major cover on the ground (Ledin and Willebrand 1995).

6.3. IRRIGATION

Irrigation is an expensive practice, and even if it can consistently increase biomass production, its cost is generally not justified for SRC (Facciotto 2005), particularly if pumping has to be done for providing the water (Berndes and Borjesson 2004). Nevertheless it may be necessary during the first year, to facilitate cuttings rooting as an emergency intervention in case of dry spring. However, it should be pointed out that high productivity can be achieved only with sufficient amounts of precipitation (or irrigation) during the growing season (Weih 2004). According to Lindroth and Bath (1999), about 1 mm/day should be available to willows during the growing season. On the other hand the high transpiration activity of SRC (particularly willow) may be used for phytoremediation of many liquid wastes such as sewage sludge (BIOPROS). This use combines the environmental service with the biomass production, leading both to an increased yield (waste liquids generally contain nutrients in variable amounts) and an economic solution for liquid urban waste disposal (Dimitriou and Aronsson 2005).

6.4. PEST AND DISEASES CONTROL

It is extremely important to keep an efficient and timely control of pests and diseases in SRC plantations. Nevertheless the chemical intervention against insects or diseases is very expensive and should be done only in case of risk for the plantation survival (Mitchell 1999).

The first, basic step for successful control is the appropriate clone choice. It has to be very carefully chosen considering the site condition and attempting to match as much as possible the clone requirements with the environmental conditions of the site. Limiting the stress due to climatic/soil factors is one of the most important key for controlling pest and disease attacks (Cambours et al. 2006). The ability to resist to the most common threats is also important. Salix viminalix clones, as an example, the most common in SRC plantations in Scandinavians and Central Europeans country are very sensitive to the leaf rust (*Melampsora Epitea*) and other species should be preferred in order to avoid widespread attacks.

A further issue related to pest control is the very structure of SRC plantations, where trees with the same genetic characteristic (generally a unique clone) are planted in high density stands, creating the best conditions for the development of pest and fungi. Some authors propose to plant mixed stands in order to reduce the potential of pest and diseases development and spreading (McCracken 2004). Mixing of different clones or species within the same plantation proved to have poor results, because in such a tight systems competition is very strong and even slight differences in growing behavior (such as retarded sprout, slower initial growth, lower tolerance to shadow) can lead to a quick die back due to competition of the less adapted clones (Berthelot 2001). Differently it could be suggested to establish in the same area pure stands (composed of the same clone) but using different clones for the single stands. Inner competition would be reduced and pest and diseases control would be easier because different clones could act as barriers to the dispersion of insects and spores.

6.7. FIELD RESTORATION

The removal of trees from the field at end of the plantation activity may be done with different techniques and different machinery according to the future use of the field. Surviving stumps can be killed using systemic herbicide during the summer or just destroyed during the winter after the last harvest. If a new culture not too exigent in terms of soil preparation is due to be planted, stools and bigger roots may be destroyed with a wide range of machinery, followed by a normal plowing (Hartsough and Yomogida 1996). By harrowing part of the remaining roots can be up taken leaving the field available for the next crop. In order to avoid risks of root diseases the establishment of a new SRC plantation a different crop should be cultivated in the field for at least one year after the removal of the old plantation (ISP 2004).

Some technological and technical properties of some SRC, as Poplar, Willow and Black Locust are presented at Table 1.

Table 1: Technological and technical properties on some short rotation coppice

Species	Willow	Poplar	Black Locust
Crop density, [1000 stems/ha]	18-25	10-15	8-12
Rotation years	3-4	1-3	2-4
Av. height at harvest, [m]	3.5-5.0	2.5-7.5	2.0-5.0
Av. butt diameter at harvest, [mm]	15-30	20-50	20-40
Growing stock at harvest, [fresh tons/ha]	30-60	20-45	15-40
Moisture content at harvest, [%]	53-55	49-52	35-38
Dry mass yield, [DM*/ha year]	8-15	9-16	5-10
Lower heating value, [MJ/kg DM]	16,7-18,4	17,7	18,5
Higher heating value, [MJ/kg DM]	18,6-20,2	19-19,7	19,5-19,9
Energy production per ha, [GJ/ha]	270-315	180-300	120-200
Ash content, [weight %]	2,0	1,5	2,5

(DM – dry mass)

CONCLUSIONS

There are potential areas and climatic conditions that favor the creation of energy plantations from suitable hybrids and branches of short rotation forestry, as such Willow, Poplar and Black Locust in our country. The minimum area for these crops, in regard to the requirements for financing under the various EU programs and funds, should be not less than 1 ha. It is necessary to pay close attention to the climatic and soil conditions of the forested terrains. In determining the location of a plantation close attention should be paid to the transport distances to the potential customers who buy biomass as this distance should not exceed 50-80 km. Our country has experience in growing intensive poplar crops for woody, technological chips, pulp and fiber production. We also have extensive experience in the breeding and growing of European and Euro-American poplar branches and some willow branches. In order to carry out soil-preparation, weed, pest and disease control, there is a proper technique existing in our country, but for cut planting, the use a high-performance and high-quality planting machines, as „Step Planter“, „Salix Maskiner AB“, „Rotor cutting planter“, „Berto“ and others is necessary.

In conclusion, in our country there are objective conditions for creation and cultivation of high yielding energy crops from willow and poplar, for output of wood chips for the production of heating and electricity.

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