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TECHNOLOGICAL OPPORTUNITIES SURVEY OF FOREST SHORT ROTATION PLANTATIONS IN BULGARIA FOR ENERGY BIOMASS PRODUCTION* PART 3: ANALYSIS OF THE TECHNOLOGIES AND MACHINES FORWOOD BIOMASS PLANTATION HARVESTING

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ABSTRACT

The present survey analyzes the key technologies for harvesting SRC plantation for production of biomass and the typical harvesters, suitable for willow, poplar and black locust harvesting in Bulgaria. The advantages and disadvantages of the various technological schemes are highlighted and some recommendations to the Bulgarian producers on their application are made.

Key words: SRP crops, biomass, harvesters, mechanized harvesting

INTRODUCTION

Short rotation coppice compares either to conventional forestry or to common agriculture is a completely new crops, posing completely new problems. Key point of SRC management is the question of how to harvest these new crops. The only market product of these plantations is fuel chips, a biomass commodity which must bear a relatively low unit price to be competitive. Manual systems, conventional forestry equipment and unmodified agricultural machinery are inefficient.

The choice of appropriate harvest technology depends on many factors. Whole stalks can be used on the short, niche market. Whole plants can be harvested in one or two stages. Two-stage technology allows the drive units to use less power than a single-stage during the harvest (Lechasseur and Savoie 2005). The smaller machines should be more useful in two-stage technologies using natural drying. The one-stage harvest technology is being recommended on large plantations and where there is a well-developed market, with the possibility of the solid biomass use for co-burning in the industrial coal combustion (Gera 2002). The wood material ground down in the modified forage harvesters can constitute the raw material for further processing in the production of briquettes or pellets. Because the particles are too large to produce durable briquettes or pellets, it is necessary to grind further the chips, obtained from the forage harvester (Bitra 2008).

1. HARVESTING TECHNOLOGIES

The harvest of energy plants takes place in the late autumn or winter, during the dormant vegetation. Unfortunately, during this period, in most regions there is bad weather or high soil moisture in the autumn or the early spring, making it marshy, or there is too much snow. The use of crawler suspension or wide tires is necessary in such conditions. Depending on the applied technology and the cutting mechanism, the snow can also be taken by biomass and can find its way to the cutting unit, and further with chips to the load-carrier of transport means. Snow mixed with chips increases their moisture, and consequently leads to more rapid digestion of biomass and its loss

(Boyd 2000). The date of harvest and its periodicity depends on plant species and the raw material harvested.

The choice of the harvest technology of energy plants depends on their species. Quick-growing shrubs and trees, which can include shrubby willow, poplar and black locust, is possible to harvest one or two stages in the annual cycles (Table 1).

Table 1: Harvest technologies and machines for energetic crops

Harvest methods of SRC plantation from poplar, willow and black locust		**Kind of Machines**
One stage	Cycle: one-year	Mounted, pulled or self-propelled forage harvesters with adapter for maize harvest, non-row dependent head preferably
	Cycle: 2-5-year	Tractor or self-propelled forage harvesters with special adapter
	Transport	Tractor volume trailers or container trucks
Two stages	Cutting; one year cycle	Secateurs, brushcutters, tractor mowers with circular saws, special cutting machines and pilling, bundling or pressing (round balers)
	Cutting; 2-5-year cycle	As for the one-year cycle of willow, plus lightweight chainsaw
	Cutting; 5-30-year cycle	Poplar: forest machinery, harvesters group, lightweight chainsaw (≤ Ø20 cm) and harvesters or chainsaws (> Ø15 cm), skidders, forwarders.
	Loading and unloading	Manual, front or grab loaders, forwarders or skidders
	Transport	Tractor trailer or cars, forest trailers
	Shredding	Wood chippers, chippers device

One-Stage Harvest: The one-stage harvest consists of simultaneous cutting plants and breaking up, mostly using a forage harvester, both tractor driven and self-propelled. This is direct method of SRC harvesting in the chips form. This technological scheme provides the best performance, but it has some drawbacks: a high initial cost and the resulting high cost of the purchase price depreciation; the need to establish large plantations, which may reduce the transport costs of combine harvester on long-distance; chipping out the possibility of wet weight of the storage environment and the extracted biomass must be burned immediately or subjected to drying, which increases the price per unit of energy obtained (Lisowsky 2010).

Two-Stage Harvest: This technology is comprised of two independent phases, which are performed by separate machines. In the first phase the plants are cut, and in the other they are broken-up. Between these phases can have several operations, depending on the plant species and forms of a material. In the case of short rotation crops, in two-stages dominates a harvest as whole plants and after drying of material, its grinding in stationary conditions.

Harvesting of SRC plants has to perform during the trees dormancy, in winter time, when the soil is frozen. This would facilitate the operation since heavy machinery on saturated fields cause soil compaction and damages the plantation and the field itself. Short rotation coppice in Bulgarian climatic conditions is best harvested from end-November to early-March. However weather conditions do not always allow for termination of harvest in this period. At that time the plant material moisture content is around 45 – 55 %, depending on the variety, region and weather conditions. Usually, the yield of willow plants is between 10 –

12 t/ha dry biomass. (Lieskovský 2012). In good weather and soil conditions and well fertilization, some good variety of annual short rotation willow plants are achieving yields of dry biomass to 18 – 30 t/ha.

2. HARVESTING TECHNIQUES AND MACHINES

The choice of appropriate plant cutting elements is a critical decision in the phase of the machines design for the harvest of energetic plants. While cutting the coppice, a working unit has the task of the simultaneous cutting of few shoots of different diameters. All shoots, growing from the snags, strive for vertical settings, also the ones which are offshoots. Cutting these offshoots requires the greater energy than vertical shoots, since they have the greater horizontal cutting surface. Diversifying cross sections of shoots among rows of plants and along rows makes harvest difficult. It is easier to cut smaller shoots, but it is possible to scroll them by moving parts of the cutting mechanism. It would apply the element taking stems down right above the cutting plain. In order to reduce the negative effect for growing again of new shoots they should be cut in the first year after seating, at about 50 mm level above the soil surface and in consecutive 100-150 mm. The result is a better separation of shoots, minimized damage to snag, reduced diseases and improved yields (Wilkinson et al. 2007).

Cutting mechanisms, which are installed on machines to harvest of energetic plants can be divided into unsupported and supported ones. In units cutting shrubs and trees there can be used disc saws, chain saws, disc knife, plates and flail knives, which is one of the unsupported units. Support cutting is used in latter units and rotational knives are common in adapters of tractor forage harvesters to harvest maize for silage.

The harvest process can be done by various techniques. The appropriate cut-off already a mature offshoots from snags is a very important element of its viability. Shoots should be cut at the height of 5-10 cm above the soil to have visible two or one dormant bud. Cut-off must be done in a sharp tool such as scissors and high-speed saw or disk knife.

Work of scissors secateurs is very inefficient and this technique can be used in particularly small plantations harvested in the one-year cycle (Savoie 2005). With very spreading shoots an additional person is sometimes needed, apart from operator, to incline and receive of cut stems. According to Kwaśniewski (2006) found that when cutting with a chain saw or brushcutters, better performance (0,024 ha/h) is achieved by employment of two helpers, than one (0,016 ha/h) (Figure 1).

Figure 1: Poplar and willow plantation harvesting with brushcutters.

The operating productivity under these conditions is significantly lower than in mechanized harvesting (0,5 – 0,7 ha/h). In respect to the risks associated with this technique of harvesting and for safety reasons it cannot be recommended. In addition, when planning a harvest one should take into account the possibility of adverse weather conditions, such as the autumn and spring sloppy, residual snow cover, which may affect the performance of manual harvesting. Real time to harvest biomass energetic plants can be much shorter than the planned and agrotechnical term. Due to the rising of labor costs harvesting by hand will be displaced by mechanical harvesting.

One-year willows can be harvested using standard machines for harvest corn. The shoots can also be harvested wholly in bulk or in bundles or bales, using a special round balers equipped with the cutting disc and the beater breaking-up units or cut-breaking-up unit (Schroeder 2008). One-year poplars and two- or three-year willows can be harvested in the form of whole stems or broken-up by forage harvesters equipped with special attachments. According to Scandinavian and Italian experience harvest of willows in 3 to 5-year-old cycles is most justified economically (Mola-Yudego and Pelkonen 2008), and poplar and 5-7 years (even 20 – 30) (Molas 2008). With longer harvest rotation cycles, plant shoots are thicker. In the third year willow shoots reach the height of 6-8 m and a diameter of 80 – 100 mm. The tree with a diameter greater than 100 mm should be harvested using techniques used in forestry. In the three-year harvest cycle of willow and two-year poplar, SRC yield can be very high and ranges 60 – 80 t/ha of wet material (moisture content around 50%). Some species such as black locust and some perennials (Miscanthus, switchgrass, reed canary grass) is possible to harvest one or two stages, but only in a one-year cycle.

The experience of countries, which is cultivated SRC are varied and recommendations with respect to harvesting technologies of energetic plants depend on many factors. From the studies carried out so far are varied and it is difficult to clearly identify and to recommend the use of a specific harvest technology. In general, the one-stage technology is recommended for large plantations, and two-stage for the small ones.

Mechanization has a key role in the economic feasibility of SRC programs since it can represent up to 70 % of the total costs of biomass production (Mitchell 1999). An efficient harvest operation and the choice of appropriate machinery is a basic assumption for successful energy farms, as well as the appropriate field design that must consider the machinery will be used. Many harvesters have been developed, mostly in Europe, specifically for SRC plantations (Table 2).

Table 2: Harvesting machinery for SRC in Europe

Model	Function	Origin	Locomotion	Power, [kW]	Weight, [kg]	Country
Fröbbesta	cut-only	cuttings harvester	pulled	70	3000	Sweden
Saf – Isma	cut-only	cuttings harvester	mounted	50	300	Italy
Optiger Ltd.	cut-only	prototype	mounted	50	600	Hungary
Lougry	cut-&-bundle	prototype	pulled	70	3000	N.Ireland
Nicholson	cut-&-bundle	cuttings harvester	pulled	65	3000	Britain
Dansalix	cut-&-extract	cuttings harvester	pulled	65	2000	Denmark
Berny	cut-&-extract	cuttings harvester	pulled	80	2000	Italy
Hvidsted	cut-&-extract	cuttings harvester	self-propelled	80	6000	Denmark
Sagerslätt Empire	cut-&-extract	prototype	self-propelled	130	12000	Sweden
ESM 901	cut-&-extract	prototype	self-propelled	74	7000	Sweden
Gandini	cut-&-chip	prototype	mounted	50	850	Italy
Diemelstadt-LWF	cut-&-chip	prototype	mounted	90	800	Germany
MBB Biber	cut-&-chip	prototype	self-propelled	52	4300	Germany
Bender I – II	cut-&-chip	prototype	mounted	85–120	950–1250	Sweden
Spaperi	cut-&-chip	prototype	mounted	120	1000	Italy
Emk – Nime	cut-&-chip	prototype	mounted	100	1700	Hungary
SV – 6	cut-&-chip	prototype	mounted	70	1950	Czech
Austoft 7700	cut-&-chip	forage harvester	self-propelled	179	12500	Sweden
Claas Jaguar HS1	cut-&-chip	forage harvester	self-propelled	330	9400	Germany
Claas Jaguar HS2	cut-&-chip	forage harvester	self-propelled	336	11500	Germany
JD/Kemper	cut-&-chip	forage harvester	self-propelled	301	11700	Britain

According to Spinelli (2006) and Verani (2008), SRC harvesting consists of four main operations: cutting (felling), collection, extraction and comminution (chipping). The main functional difference between harvester types is the number and the type of operations that they can perform. In order of growing degree of integration, the following functional types can be described

***Cut-only harvesters*:** The harvesters cut and fell the stems, laying them in windrows or heaps. Cut stems are then collected by a separate unit, which delivers them to a chipper (Figure 2). For stems logging, the circular saw and felling device harvesters are equipped with. A special front loader collects the stems subsequently. As an alternative a chipper or chip-forwarder can be used to collect, chip and extract in one pass.

Figure 2: Cut-only (simple) harvester. SAF – ISMA prototype on two years old poplar

Cut-and-bundle harvesters: Harvesters cut the stems and collects them in bundles or round bales. Stem bundles or stem bales are dropped on the field, like hay bales (Figures 3 and 4). They are later collected by a separate unit, most often a conventional forwarder or a farm tractor with forestry trailer.

Figure 3: Bundler's prototype – Nicholson cut and bundle harvester

Figure 4: New Holland prototype cutbaling machine

Cut-and-extract harvesters: Harvesters cut the stems, collecting and loading them over a deck of own frame (Figure 5). Machines harvest the entire stems and collect them in the back flatcars. Then, the machines unload stems to the field edge or to any suitable landing. Chipping is the only operation delegated to separate units.

Figure 5: Sagerslätt Empire cut and extract prototype on willow

***Cut-and-chip harvesters*:** The harvesters cut, collect and comminute the crop, delivering the chip at the field edge. In alternative, the extraction can be delegated to chip shuttles, to keep the harvester going. This is direct technology. Chip shuttling is used preferably when the extraction distance is large (Figure 6).

a

b

Figure 6: Cut and chip harvesters: a) Claas Jaguar with adapter HS1 on 1 year old poplar; b) Salix Maskiner mounted Bender 6WG forage harvester with a chainsaw on 3-years welow

Cut-and-chip harvesting system is by far the most common type and within it the forager system is the prevalent method for harvesting short-rotation plantations. The system is based on a modified forage harvester, whose standard header is replaced with a special SRC header – wood-harvesting adapter, as shown in Figure 7. The harvester is assisted by 2 to 4 tractor-trailer units, which receive the chips and move them to a landing (Spinelli 2008). As a typical work scheme, the tractor-trailer travels by the side of the harvester which is blowing the chips perpendicularly to its moving direction. The number of tractors depends on the productivity of the harvester and the distance of the field to the collection point. In a properly organized work the harvester, the most expensive machine of the system, never stops for lack of empty trailers.

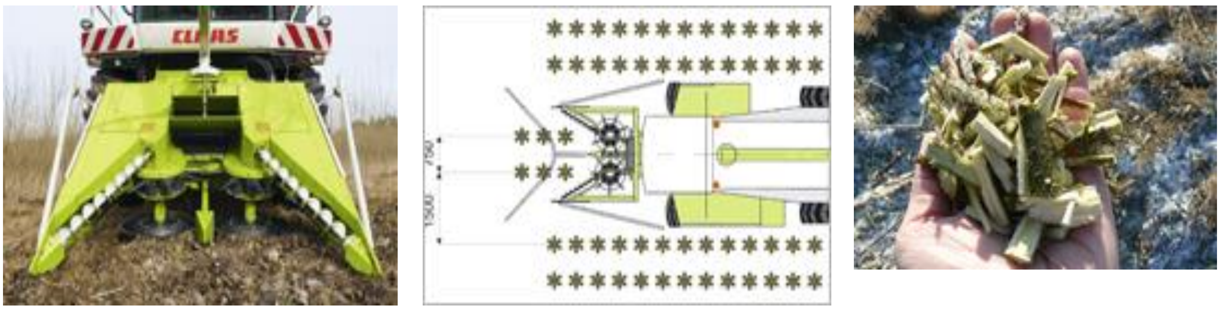

Figure 7: Wood-harvesting adapter HS-2 for Claas Jaguar 900 forage harvester

3. STORING AND TRANSPORTING OF BIOMASS

As already mentioned biomass harvest of SRC crops is harvested during winter months, within a short operation window. If the demand for fuel is available, chipped wood can be conveyed directly to the end user. It should be noted that freshly harvested biomass has a high content of water (about 50 %) which tend to decrease its market value (Facciotto 2005): a high content of water reduces dramatically the energy value of the biomass. In many cases the market demand is not enough to adsorb quickly the whole production of harvest, which must operate in a short time span. Those factors may lead to the necessity of storing the biomass for periods that may vary from some weeks to some months. This can be a solution working as a buffer (waiting for the market to demand the fuel) and as a mean for reducing the water content, in order to enhance the biomass quality and obtain a better price from the end user. According to the different harvest system, three cases can be described based on the product of kind that is delivered from the field:

1. Whole stems. Those can be easily stored in the headland or in the farm yard. Within a few months the stems loose a variable percentage (20 – 40 %) of water content with limited reduction of biomass, mostly due to branches and tops broken in handling operations (Nurmi 1995). Whole stems are difficult to transport, particularly for long distances, thus previous to delivery they should be chipped. Otherwise this operation has to be done by the end user and small enterprises will unlikely have an own chipper machine.

2. Bundles and bales. Can be stored exactly as the stems but their handling and transportation is much more efficient. Those as well have to be chipped by the end user, but their shape makes normal chippers to use. Hammer mills are the most suitable solution for this material, but such an equipment can be found only in big power or combined heat and power (CHP) plants, limiting the possible end users to a few or a single one in the area

3. Chipped wood. This is the most common product of SRC harvest. Its bulk density is very low (about 350 kg/m^3) and this factor, coupled with the high water content, make generally uneconomic to transport fresh chip wood for distances longer than 50 – 80 km. Chipped wood can be easily stored in piles but if not covered it is unlikely to loose humidity because comminuted wood adsorb water from meteoric water (Lehtikangas 2000). Also soil surfaces should be avoided because soil moisture would be adsorbed by the chips. Piles require a careful management because internal fermentation can cause combustion. Fermentation processes cause a loss of biomass up to 20 % and even fuel quality is reduced (Jirjis 2005). In order to avoid these processes the piles should be periodically moved (with a front loader) and possibly covered by a shed or a plastic cover in order to improve water content reduction.

Transportation of biomass is an important issue and may determine the profitability of such a crop. According to Cormier (2006) the approximate transportation cost for delivery of fresh wood chips from SRP plantations varies from a minimum of about 9 CAN $ to over 45 CAN$, considering transportation by truck on paved roads (over 90 % of the haul distance) and including the time of loading and unloading. The relationship between the chips price of the material and the transport distance is shown in Table 3.

Table 3: The relationship between the chips price of the produced material and the transport distance

Distance, [km]	Cost per ton of fresh chip wood at bulk density 350 kg/m^3, [CAN $/EURO]
25	9,35/12,00
50	12,80/16,43
75	16,25/20,86
100	19,65/25,22
150	26,50/34,02
200	33,40/42,36
300	47,10/60,46

According to the price the end user is disposed to pay for the biomass and the production costs, the delivery cost may play a key role in limiting the area actually exploitable for SRC production. Based on the European and Canadian experience, it is to expect that haul distances for chip wood cannot exceed the limit of 70 – 80 km.

CONCLUSIONS

The three suitable climatic zones for SRC growing in our country (Continental, Panonnian and Mediterranean North), as well as the wide variations in the altitude, also determine various agro-technological deadlines in the autumn-winter season for harvesting of the biomass from the energy crops. For harvesting crops with area less than 1 ha and up to one year, the use of tools such as brushcutters and scissors secateurs is more efficient. For harvesting of crops with an area of over 150 ha the direct harvesting is more effective.

Main advantages of direct biomass harvesting are:

1. only one operation – cut and ship;
2. better use forage harvester – longer operating season;
3. better for direct delivery.

Disadvantages of direct harvesting are:

1. wet chips – almost 50% moisture;
2. loss of dry matter when stored more a few days;
3. problems with fungi, when handling chips after storage;
4. needs more machinery and staff at harvest.

Two-stage harvesting technology with hole-stem harvester (cut and extract harvester) requires less starting investments from the farmers. This system is suitable for the Bulgarian conditions where the farmers need to gain some experience in growing energy plantations and it is risky to put greater investments in larger areas and the implementation of one-stage harvesting.

Main advantages of the two-stage technology with hole-stem harvester are:

1. minimal dry mater loses;
2. more boilers can use the dry chips – less than 30 % moisture;
3. one man harvest operation.

The main disadvantage is: needs more than one operation – harvest, chipping and some additional handlings.

After acquiring the necessary experience from Bulgarian farmers and relevant market conditions one can proceed to cut and bundler harvesting or one stage (direct) technology modified forage harvesters, equipped with wood processing adaptor.

It can be concluded that for the Bulgarian conditions, in the early stage of the development of willow and poplar SRC plantations, the two-stage technology and whole stem harvesting is more suitable.

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