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OBTAINING BIOMASS FROM ENERGY WILLOW, A SOURCE OF THERMAL ENERGY FOR RURAL AREAS

[1–4.] INMA Bucharest, ROMANIA

Abstract: Biomass plays an important part in the National Action Plan for Renewable Energy, which is developed within the frame established by the Directive for Renewable Energy. The main biomass use is for heating buildings (houses, schools, dispensaries, kindergartens, etc.) in small communities, which will use approximately 80% of the total production, the remaining 20% of biomass can be used for producing biofuels (12%) and electric energy (8%). The paper presents the harvesting and chopping manner for energy willow plants (Salix viminalis) in the purpose of obtaining the necessary wood chips for feeding thermal plants in rural areas.
Keywords: biomass, energy willow, renewable energy, blade cutter

1. INTRODUCTION

Energy willow crops for biomass determine the increase of habitat diversity, being situated in agricultural areas, and not in forestry exploited surfaces. These crops can capitalize sloping terrains, fixing the soil and improving its quality, can fulfil a soil bioremediation role, extracting excess ions and can be used to give back the productive cycle of heavily degraded lands (waste dumps, saline, eroded, sandy soils, etc.) (Ion V.I., 2006). Willow can be transformed in a variety of non–polluting and sustainable resources including (Arion et al., 2008):

» Heat and electricity through direct combustion, combustion together with coal and gasification;
» Biodegradable plastic and other polymers;
» Biofuels.

Energy crops for biomass can be harvested repeatedly 10–15 times before being necessary to replant them. The cost of maintenance works for willow is reduced, compared to classic agricultural species, using reduced quantities of pesticides. The production of biomass from willow reduces the need for fossil fuels and petrol products (Găgeanu I. et al, 2015).

Harvesting is performed beginning with year 2 or 3, in winter, when the dry substance has maximum value and the quantity of water in stems is reduced. Costs for establishing a hectare of willow for biomass varies depending on the type of planting material used, the terrain on which the crop is situated, the level of mechanization and the technology adopted (Păun A. et al., 2015).

Dry matter production from willow can vary depending on the species, soil type and growth cycle. In the first 3 years from planting, production varies between 15–45 t/ha, in the next 3 years between 22–70 t/ha. Salix viminalis grown in a loamy soil with fertilization treatment shows the same yield in both cycles (45–70 t/ha) (Găgeanu P. et al., 2014). Average stem diameter in the second cycle varies between 24–39 mm and stem height between 2.2 and 5.4 m. The number of stems per plant is 6–11 with an average of 8 stems per plant in a favourable environment. The variation of stem diameter is between 20–80 mm and many plants have a lot of smaller stems. The recommended cutting height is between 100–150 mm from the ground in order to avoid trunk destruction. After this period, stem and leaf density becomes very big, reducing light towards the lower part and reducing growth potential.

The thermal energy that can be obtained from this source ensures heating for 145.000 conventional apartments annually. By extending energy willow plantations, besides representing a source of

renewable energy, energy willow reuses terrains that were left unused, avoids (or reduces considerably) deforestation generated by the increasing need for cheap fuel [11].
Energy willow harvesting can be achieved manually or mechanized. Manual harvesting is very little used and only on small surfaces. Mechanized harvesting is used in the case of larger surfaces, with special equipment that are chosen depending on the size of surfaces that need to be harvested: from simple (and cheaper) equipment that can harvest approximately 50 ha / season, to more complex and robust equipment (but also more expensive) that can harvest 300–350 ha / season or even combines with a device adapted for willow, which are only profitable on large surfaces (800–1000 ha / season).
Depending on the manner of harvesting stems, they can be harvested as long stems, as wood chips of different sizes and as bales.
Equipment for harvesting energy willow in the form of wood chips can be self–propelled or towed. Through their construction, they can achieve willow harvesting on simple or double rows. The characteristic for this type of equipment consists in the fact that after cutting the stems, they are chopped into 2–10 mm fragments, and the wood chips obtained are loaded directly into technological trailers. Energy willow stem harvesting in the form of wood chips is the method most commonly used in Europe, especially for producing energy through gasification and combustion. For this, moisture has to be reduced to less than 30% in order to produce energy. Chopped wood can also be used for the paper industry or for pressed wood, without requiring other treatments.

2. MATERIAL AND METHOD

Harvesting and chopping energy willow plants is performed using specialized technical equipment for cutting, feeding, chopping and throwing energy willow. The thickness of plants that can be harvested and chopped is between 10 and 70 mm. Besides energy willow crops, the same equipment can be used for harvesting other crops whose plants can be used as biomass, complying with the conditions imposed for the maximum thickness of plants that can be harvested.
Towed or carried during transportation and operation type of technical equipment for harvesting and chopping energy willow (Figure 1) are destined to work in aggregate with agricultural or forestry tractors on wheels with a power of approximately 150 HP, being driven from the tractor's PTO. This type of equipment is used for harvesting and chopping energy willow stems. The machines operate on two rows at a distance of 0.75 m between them and the free space between two planted rows is of 1.5 m. There are also some technical equipment adapted for coupling to combines destined for harvesting cereals and technical plants. By using the same combines in winter, the downtimes during winter are removed, because energy willow is only harvested in winter.

Figure 1. Types of technical equipment for harvesting energy willow [10, 12]
a) Towed harvesting & chopping technical equipment, b) Carried harvesting & chopping technical equipment

An equipment for harvesting energy willow is mainly built of the following subassemblies: cutting–feeding station, chopper–thrower with conveying system, hitch, plant bender, cardan shaft and coupling pieces. In the case of carried equipment, the rolling system, hitch, cardan shaft and coupling pieces are missing.
Stem cutting is achieved by two saw blades made from hard metal that can cut stems up to 1000 mm in diameter. A hydraulic or mechanically driven arm pretensions stems, bending them forward. Thin stems protruding from the main stems are directed towards the cutting discs. After being cut, stems are taken by two drums fitted with pulling fingers or with serrated blades, directing them towards the feeding device of the chopping device.
Specific for all energy willow harvesting equipment is the fact that the two saw discs for cutting stems overlap on a certain portion and the pulling drums are provided with fingers or pallets that improve the process of pulling in the cut stems (Figure 2 a, c). There are also equipment with a single drum and a cutting

blade, which has a diameter of up to 2000 mm. The cutting disc is divided in multiple sectors, which in care of deterioration can be easily replaced. (Figure 2 b).

Figure 2 – Types of drums with cutting and pulling disk [13]
a) with serrated pallets and fingers; b) with single segmented cutting blade; c) with serrated pallets

Plant chopping is performed using chopping devices or choppers, which have the role of taking willow stems transported by the feeding system, of chopping (fragmenting) them to the desired length and throwing them due to the peripheral speed towards the equipment's evacuation system.

The chopping devices used need to fulfil the following technological requirements:

≡ To ensure that the material is chopped on the prescribed length (usually between 3 and 100 mm, depending on the technology employed);
≡ To achieve an adequate evenness of the wood chips length.

From a constructive view, the devices for chopping willow are of the type with blades fitted rigidly on the driving element. They can be: with tangential blades or with radial blades.

Chopping devices with blades fitted rigidly on the driving element show high safety during exploitation, ensure high uniformity for the chopping length and allow a precise adjustment of the chopping length. These devices are characterized by the fact that they have active elements (the blades) fixed rigidly through the means of screws on the support elements, which, depending on the shape, can be:

≡ Chopping devices with blades fitted on a drum;
≡ Chopping devices with blades fitted on disc.

The chopping devices with blades fitted on drum (called cylindrical drums) are composed of the following main parts: drum with blades, the housing (case) of the drum and the counter blade. In case the drum also performs the throwing of the chopped material, the blades are executed in the shape of spiral pallets or throwing pallets are fitted on the supports of the blades.

The counter blade in fixed on the housing of the chopping device and is set parallel to the axle of the drum, and the space between the blade and the counter blade is 0.3…1 mm. Experimentally, was established that the distance between the elements of the cutting pair (blade and counter blade) has an energetic influence on the cutting process. The specific energy consumption increases along with increasing the distance between the blade and the counter blade, due to the fact that setting of the plants on the counter blade is done at a certain distance from the cutting section and therefore, the bending of the rods occurs.

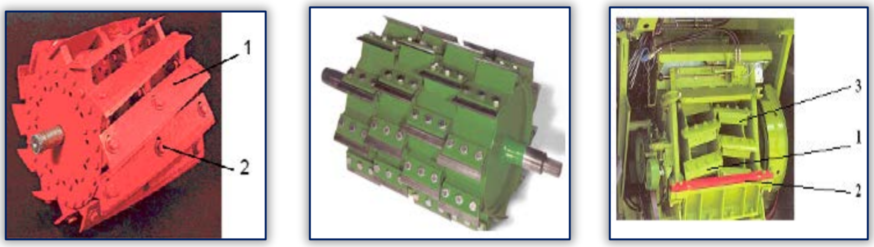

Figure 3 – Types of cutting drums. a) Chopping drum with spiral blades (New Holland 770); 1–spiral blade; 2–fixing screws; b) Chopping drum with cascade blades (John Deere 3760); c) Drum with two rows of V placed blades (CLAAS); 1–blade; 2–counter blade; 3–pallet

The space between the blade and the counter blade has a smaller influence in the case of well sharpened blades and of thick plants. Another important factor in decreasing energetic consumption is constituted by the thickness of the blade's edge and its maintenance for a period as large as possible. Edge thickness is recommended to be maintained within the interval of 15…150 μm, a fact for which the combines are fitted with special devices for sharpening the blades, placed directly on the drum. Sharpening is performed by rotating the chopping drum in the opposite direction and approaching the abrasive stone to the blade device.

The diameter of the chopping drum at the periphery of the blades is of 250…800 mm, and the peripheral speed is of 19…35 m/s for drums with tangential blades that only perform the chopping and up to 38 m/s for drums that both chop and throw the chopped material. The blades are placed inclined to the drum generator, at an angle of 6…12^{o} in order to achieve a progressive cutting, and the edge is sharpened to an angle of 16…37°. In case the chopping drum also throws the chopped material, the blades are built in the shape of spiral pallets or throwing pallets are fitted on the blade support.

The chopping devices with blades fitted on disc are composed of: blades for chopping the material, feeding inlet, discs, pallets for throwing the chopped material and housing.

Blades can have straight or curved edge and can be placed inclined to the rotation plane of the blade. Blades with a straight edge are more common, are easily manufactured and sharpened being placed inclined to the radial direction. Feeding the chopping device with material is done on the axial direction where the feeding inlet is found. The length of the feeding inlet is $L = (0.7…0.8)R_d$ (R_d being the maximum radius of the disc, at the edge of blades). The number of blades fitted on the disc is 2…12, and the disc's speed of revolution in 500–1000 rot/min. Chopping devices with blades fitted on the disc are used for attachable harvesting equipment (towed or carried).

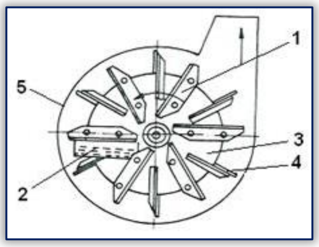

Figure 4 – Chopping device with blades mounted on disk [12, 13], left – constructive diagram; right– version built by Ceahlăul Piatra Neamț company. 1 – blades for chopping the material; 2 – feeding inlet, 3 – disc for attaching the blades, 4 – pallets for throwing the chopped material; 5 – housing.

3. RESULTS

Experiments were performed using a technical equipment for cutting and chopping energy willow with chopping device having the blades fitted on disc. The equipment is so designed as to operate in aggregate with a 150 HP agricultural tractor, being attached to its PTO according to the technological diagram show in figure 5.

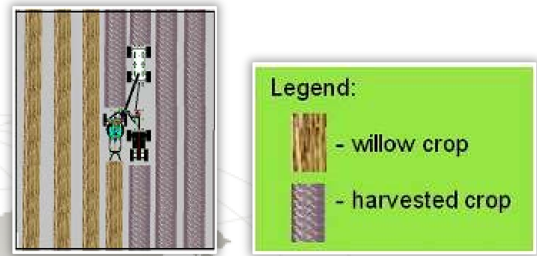

Figure 5 – Technological diagram for the equipment for harvesting and chopping energy willow

The rotation movement from the tractor's PTO is transmitted through the means of two cardan transmissions, one being of the type with safety coupling and a transmission with trapezoidal belts to the axle of the chopper, from where, by the means of a transmission with trapezoidal belts will transmit the movement to the auger of a redactor that is engaged with two auger wheels obtaining their rotation in opposite directions, directions that need to be transmitted to the cutting discs and to the feeding rollers for introducing the chopped material in the chopper.

From the two auger wheels, the movement is transmitted to the feeding rollers and the speed of revolution that is transmitted to the cutting discs is of 1063 min^{-1}, obtained through a multiplication with the help of two pairs of gears fitted on the reducer.

When the tractor is set into motion, it pulls the equipment which enters the willow crop according to the technological diagram and the operation of bending the plants forward by the plant bender starts, the plants being maintained in this position until they are cut by the cutting discs and directed forward by the two pairs of pulling rollers which grab the cut plants transporting them to the feeding inlet of the chopping device.

Once the plants reach the inlet of the chopper, they are cut by the blades fitted on the chopper's disc. The fragmented material passes behind the disc through the windows created for each blade and is taken by the pallets fitted behind the disc, pallets representing the chopper's ventilator.

Once they reach the pallets, the fragments are taken and thrown through the chamfer for directing the wood chips towards a means of transportation situated behind the equipment.

Measurements were taken for the traction force and for the torque at the PTO on a concrete track and on uneven ground for different speeds of transportation, the results being shown in the diagrams obtained from specific transducers and tensometric sensors fitted on a special bar on which the technical equipment for cutting, feeding and chopping was fitted on. The diagrams obtained are shown in the graphical representations shown in figure 6 and 7.

Material chopping was ensured in good conditions, the wood chips resulted fitted in the required sizes. The shape and size of wood chips is shown in figure 8. The size of wood chips was determined using the Retsch AS 200 BASIC sieving system (Figure 9). Sample weighing was achieved using the Mettler PM 6000 non automated weighing device, as shown in figure 10. Results from the sieving operation are presented in table 1. The graphical representation of results is given in the chart shown in figure 11. Plant cutting and the cutting height (remaining stub) is shown in figure 12.

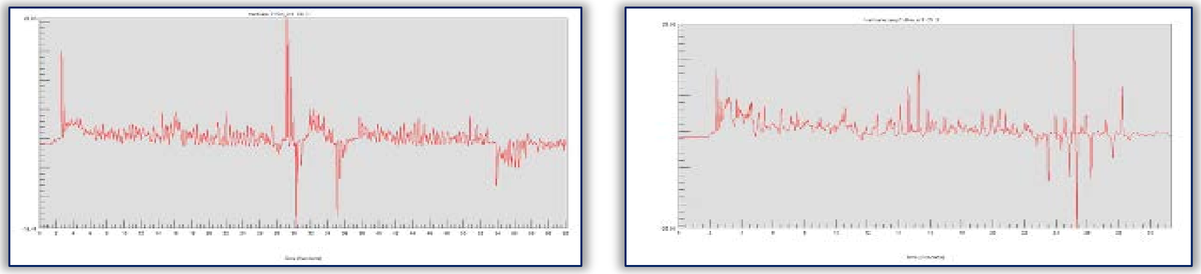

Figure 6 – Average traction force
a) On concrete track at an average speed of 21 km/h; b) On uneven ground at an average speed of 15 km/h

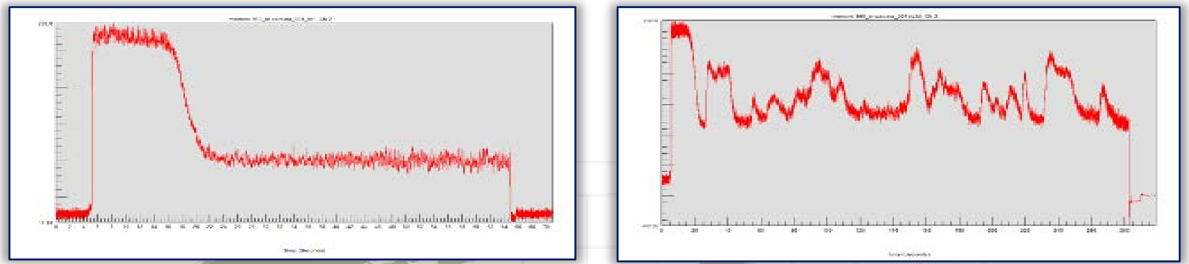

Figure 7 – Average torque at PTO. a) at 950 rot/ min without load; b) at 950 rot/min with the TE mounted

Figure 8 – Wood chips

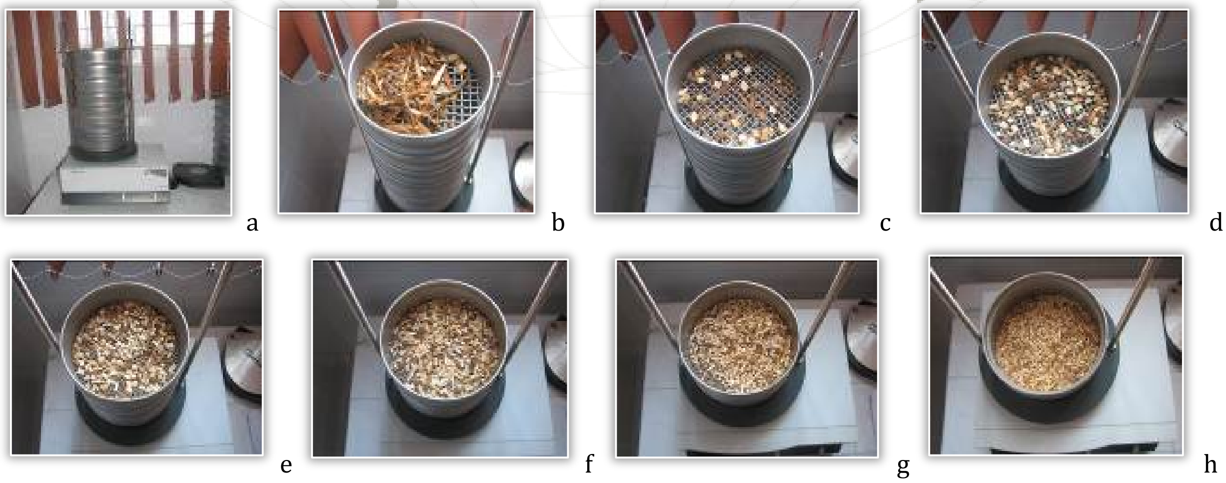

Figure 9 – Separating the chopped willow on fractions. a – Retsch device AS 200 BASIC; b) wood chips>10 mm; c) wood chips >8<10 mm; d – wood chips >6.3mm<8mm; e) wood chips >5<6.3mm; f – wood chips >4<5 mm; g) wood chips >3.15<4 mm; wood chips <3.15 mm wood chips >3.15<4 mm; h) wood chips <3.15 mm

Table 1. Chopped willow size distribution

Sample no.	Chippings size						
	φ<3.15	3.15<φ<4	4<φ<5	5<φ<6.3	6.3<φ<8	8<φ<10	φ>10
Sample 1 (g)	73.7	26.6	26.9	24.8	21.7	12.3	64
Sample 2 (g)	50.7	21.2	19.3	14.5	11.7	6.2	126.4
Sample 3 (g)	53.1	25.8	28.2	27.8	27	14.2	73.9
Sample 4 (g)	62.8	34.3	32.7	27.9	23.1	11.5	57.7
Average (g)	60.075	26.975	26.775	23.75	20.875	11.05	80.5

CONCLUSIONS

After performing the tests on the equipment for cutting, feeding and chopping energy willow, the following resulted:

≡ The equipment for cutting, feeding and chopping works in aggregate with the 150 HP tractor. Wood chips evacuation can be made in a trailer that can be coupled to the equipment and towed simultaneously with it, or it can be towed by another tractor that moves parallel to the first tractor.

≡ The drum type chopping device with cascade blades performs a good plant chopping simultaneously achieving a good evacuation of the chopped mass.

Figure 10 – Weighing the chippings using Mettler PM 6000 device

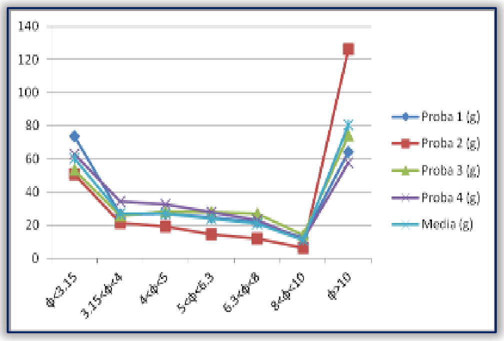

Figure 11 – Fraction distribution of the chopped biomass after separation

Figure 12 – Cutting height and remaining stub after harvesting energy willow

≡ Total material losses are not big, they do not exceed 3% in normal exploitation conditions;

≡ By analysing the quality of the chopped material, it is found that the particles with a length up to 3.15 mm represent 24.03 % of the chopped mass, 32.98% is represented by particles with the length between 3.15 and 10 mm, and 32.2 % of the wood chips are larger than 10 mm, this in the conditions of a theoretical chopping length of < 50 mm, provided in the execution documentation. By accident, there are also fragments larger than 50 mm, but insignificant compared to the mass of wood chips.

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