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FAST-GROWING POPLAR CLONES PRODUCTION OF BIOFUEL FEEDSTOCK ON MARGINAL LANDS

Mykola M. KHARYTONOV[1] **Iryna V. RULA**[1]
Yaroslav D. FUCHYLO[2] **Margaryta V. SBYTNA**[2]
Nadiia V. MARTYNOVA[3]

Abstract: *The yield of standard annual cuttings from the mother poplar plantation remains high enough for the 15th year in such clones as ´Ijzer-5´, ´Robusta´, ´Tardif de Champagne´, and ´San Giorgio´. Clones ´Ghoy´ and ´Dorskamp´ showed a high level of survival (47 and 80%, respectively) after planting in phytomeliorated mix of loess-like loam and red brown clay in the Dnipropetrovsk province. The differences in the thermal characteristics of the samples of tested cultivars reflected in changes in the composition of extracted substances caused both genetic, climatic, and soil conditions.*

Key words: *poplar, clones, biofuel feedstock, lands.*

1. Introduction

The intensive development of technologies for creating artificial forest plantations of fast-growing trees on marginal lands is associated with the production of biofuel feedstock [3], [5]. An advantage of some fast-growing plants (poplar and willow) is the ability to produce a significant amount of biomass in a short period of time [4], [7], [10]. Intensifying forest management has the potential to alleviate pressures of competing land uses and suggests that intensive management of hybrid poplar could be financially viable [1]. Choosing a strategy for growing energy poplar involves the selection of suitable genetic material and developing management technology. For example, to produce clear wood without compromising growth rates, increased net photosynthesis of residual foliage, nitrogen foliar concentrations and reduced total non-structural carbohydrates reserves of roots of hybrid poplar, the technology of removal of 1/3 of the lower crown in summer is often used [12]. Due to compensatory leaf growth and slightly increased rates of photosynthesis, defoliation does not significantly reduce trunk diameter and height growth [11].

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[1] Dnipro State Agrarian and Economic University, Serhii Yefremova no. 25, Dnipro 49600, Ukraine;
[2] Institute of Energy Crops and Sugar Beet of NAASU, Klynychna no. 25, Kyiv, 03141, Ukraine;
[3] Oles Honchar Dnipro National University, Gagarin av. no.72, Dnipro, 49010, Ukraine;
Correspondence: Mykola M. Kharytonov; email: kharytonov.m.m@dsau.dp.ua.

Nitrogen content increases in leaves following partial defoliation, but it is accumulated in a non-photosynthetic form [18].

Wider spacing and pruning can improve the water use, light, and nutrient cycling processes in short-rotation coppice with poplar or other fast-growing species to provide fuelwood and environmental benefits [6].

As a rule, typical woody biomass contains 40-50% cellulose, 25-35% hemicellulose, and 10-40% lignin [13], [20]. The pyrolytic conditions and heating rate affect the chemical reactions responsible for producing various chemical compounds present in bio-oils [2], [17]. Moreover, extractives significantly contribute to wood properties, such as mechanical strength and color [14]. That is why the amount and type of these extractives generally affect the wood quality [15].

The establishment of poplar industrial plantations requires a large amount of uniform planting material which is obtained by cuttings. Rooting of cutting is a complex process comprising a set of physiological responses to mechanical injury, wound repair, and organ development [19]. There are several techniques which improve rooting of cutting: pre-planting warming, growth stimulators treatment, biochar application, etc. [8, 9], [16]. Taking into account such important factors as the genetic component, growing technology, and environmental impact, the main goal of this work was to study the ability of numerous varieties of poplar to produce enough wood biomass for the production of fuel briquettes.

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2. Material and Methods

The first part of the research was carried out on two experimental sites located in the 123 block of the Boyarsky forest district of the Boyarka scientific station under forest-steppe zone conditions. Cuttings were planted in the ground vertically and at a 45° angle. Three years later, some of the three-year-old saplings from the six cultivars with the highest growth rates were dug out and planted nearby on the second experimental site. The saplings were planted in holes of 0.5 x 0.5 x 0.5 m size at a distance between their centers of 3.0 x 3.0 m. The height (using a rail) and the diameter at a height of 1.3 m (with a caliper) of all the plants in each cultivar were determined during the survey. Dominating among those represented in the collection of clones were such forms and hybrids of black poplar as: ´Ijzer-5´, ´Ghoy´, ´Dorskamp´, ´Marilandica´, ´Robusta´, ´Blanc du Poitou´, ´Tardif de Champagne´, ´Vereecken´, and ´San Giorgio´.

The second part of the study was carried out under steppe zone conditions in the Pokrov land reclamation station of DSAEU from 2019. In the first year, the survival degree of the saplings and their development intensity were studied.

The plot substrate in the reclaimed mineland was a mixture of loess-like loam and red-brown clay which had passed through a long-term phytomelioration stage. A comparative thermogravimetric analysis of poplar wood clone samples grown in different soil substrata was carried out to obtain the wood thermal stability information. The analysis was performed using the derivatograph Q - 1500D of the “F. Paulik - J. Paulik - L. Erdey” system. Differential mass loss and heating effects were recorded. The results of the measurements were processed using the software package supplied with the device. Samples of annual wood were analyzed dynamically at a heating rate of 10°C/min in an air atmosphere. The mass of samples was 100 mg. The reference substance was aluminum oxide.

3. Results and Discussion

Research on the pruning effect on the three-year-old trunks showed that it is possible to obtain a significant amount of wood mass in poplar plantations (Table 1).

The highest performance indicators of three-year-old wood mass from a single tree were found in cultivars ´Vereecken´ and ´Dorskamp´ . The results of two morphometric indicators studies of 5-year- old unchipped and truncated poplar trees shoots are shown in Table 2. The most intensive growth was observed in the clones ´Dorskamp´ and ´Robusta´. Less intensive growth at the age of five occurred in the clones of ´Tardif de Champagne´ , ´Blanc du Poitou´ , ´Ijzer-5´, and ´Ghoy´. High cutting (at a height of 1.3 m) provided a much larger number of shoots and their large size.

The clones ´Ghoy´ , ´Dorskamp´ , and “Sun Giorgio”' had the greatest ability to get shoots. Cultivars of other studied clones occupied an intermediate position in terms of growth rate. A study of the productivity of the mother plantation of poplars on the experimental site of the Boyarsky forest district with the determination of the cuttings yield gave the following results (Figure 1).

The yield of standard annual cuttings from the mother poplar plantation has remained high enough for the 15th year in such clones as ´Ijzer-5´ ´Robusta´, “Tardif de Champagne”, and ´San Giorgio´ . It has significantly decreased in the remaining clones (´Vereecken´ and ´Heidemij´) compared to the data at the age of eight years. This was caused by the weakening and dying of mother trees to a large extent.

Table 1

Morphometric indicators of 3-year-old wood mass of various poplar clones after trunk pruning

Clone	**H [cm]**			**Total**	**D [cm]**	
	Year				**at height**	
	First	Second	Third		0	0.5h
Ijzer-5	194.5	239.5	189.5	623.5	6.6	3.0
Ghoy	138.0	205.3	107.3	450.7	3.5	1.8
Dorskamp	297.0	250.0	212.3	756.7	8.0	3.8
Heidemij	263.5	241.5	152.0	657.0	6.4	2.9
Robusta	232.2	250.2	193.8	676.2	6.4	3.1
Blanc du Poitou	202.0	261.0	230.0	693.0	6.6	3.1
Tardif de Champagne	202.0	260.0	201.0	663.0	7.0	3.5
Vereecken	288.0	267.0	235.0	790.0	9.1	4.2
In average	216.5	218.5	168.7	603.5	6.6	3.0

Table 2

Morphometric indicators of 5-year-old uncut and cut poplar tree shoots

Clone	**Unchipped poplar trees**		**Shoots on truncated trees: units/H_{max} [m]**	
	D [cm]	**H [m]**	**truncated on H 1.3 m**	**truncated above ground level**
Ijzer 5	5.4±0.71	7.2±0.62	-	-
Ghoy	4.5±0.64	6.5±0.35	14.2/1.59	-
Dorskamp	8.6±1.00	8.9±0.52	11.4/2.06	3.0/1.34
Heidemij	5.0±0.52	8.1±0.47	5.2/1.40	4.6/1.06
Marilandica	4.6±0.41	6.1±0.55	5.2/1.20	3.9/1.17
Robusta	5.9±0.69	9.0±0.44	8.5/1.72	3.6/1.32
Blanc du Poitou	5.7±0.41	8.0±0.25	8.3/2.00	3.8/1.87
Tardif de Champagne	5.4±0,36	8.0±0.22	5.7/1.16	3.8/1.24
Gelrica	5.0±0,65	7.2±0,61	6.6/1.49	2.6/1.56
Serotina	4.4±0,28	7.0±0,20	7.5/2.02	4.2/1.74
V-235	3.3±0,40	6.6±0,53	-	-
Rochester	4.4±0,64	6.6±0,57	3.0/1.82	-

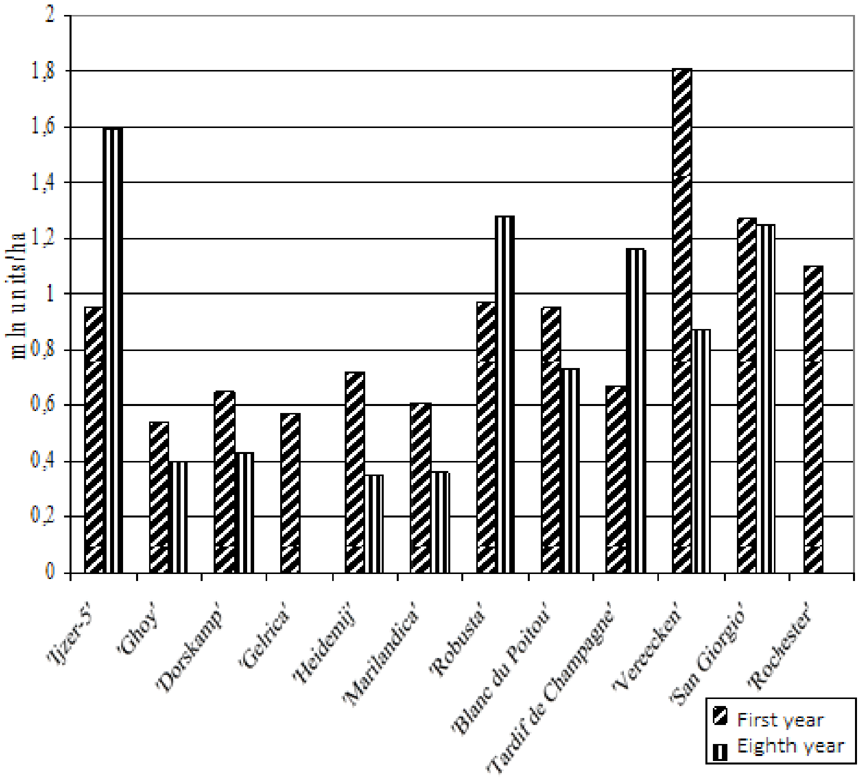

Fig. 1. *The yield of standard annual cuttings from the mother poplar plantation*

The description of thermolysis processes of six poplar clones grown at the Boyarka experimental station is given in Table 3. Thermal decomposition of wood clones of poplar grown at the Boyarka experimental station began at a temperature of 30-500°C. The first stage of decomposition of volatile components and water evaporation was the longest in the case of ´Dorskamp´ wood combustion. At the same time, the speed of the burning process in the ´Dorskamp´ clone wood was the lowest. The ´Heidemij´ and ´Vereecken´ clones had the lowest moisture content in the wood and the highest speed of passing the initial stage. The initial stage of thermolysis took place with heat absorption and the presence of endothermic effects on the DTA curves (Figure 2).

Destruction of the main components of wood (hemicellulose and cellulose) took place in the temperature range 190-400°C. A high content of hemicellulose in the wood led to their delayed? decomposition. The ranges of decomposition of hemicellulose and cellulose were superimposed on each other.

Table 3

Thermal features of poplar clones wood decomposition

Cultivar	**Stage**	**Interval [°C]**	**Extremum point, [°C]**	**Max. rate [%/min]**	**Weight loss [%]**	**Share of residual mass [%]**
Dorskamp	I	50–210	110	7.0	5.86	
	II	210–420	320	40.0	64.44	
	III	420–580	430	2.8	25.33	4.37
Blanc du Poitou	I	40–200	100	7.6	5.63	
	II	200–430	320	38.4	69.14	
	III	430–550	450	3.0	19.30	5.93
Heidemij	I	30–150	110	7.8	5.43	
	II	150–380	290	31.0	58.09	
	III	380–550	450	8.8	28.14	4.73
San Giorgio	I	40–170	90	7.8	6.03	
	II	170–380	310	39.4	61.10	
	III	380–550	450	8.8	28.14	4.73
Robusta	I	40–190	80	7.6	7.27	
	II	190–380	300	49.6	60.20	
	III	380–570	450	7.2	29.49	3.04
Vereecken	I	30–180	90	8.0	6.80	
	II	180–370	290	36.4	56.40	
	III	370–570	440	8.0	30.60	6.20

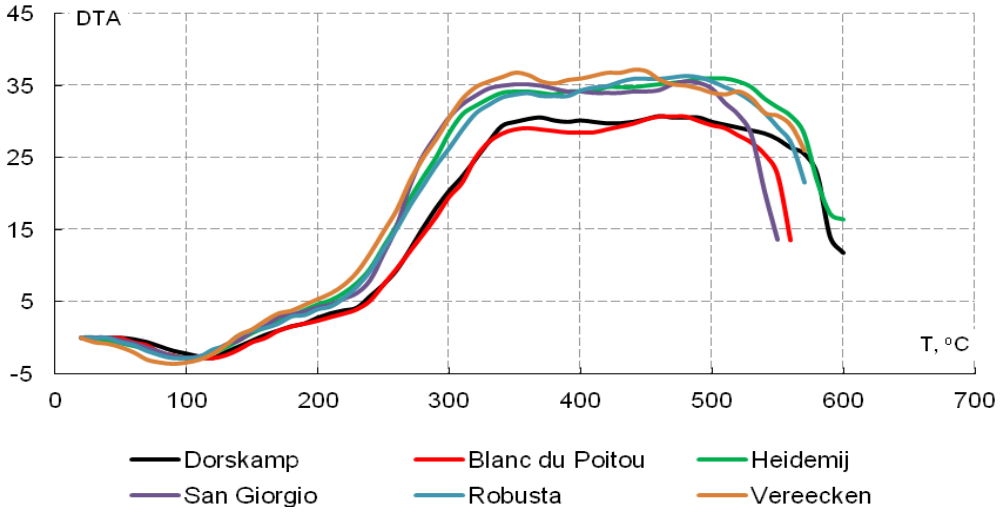

Fig. 2. *DTA curves of poplar wood thermal decomposition*

As a result, only one extreme point is observed on the DTG curves (Figure 3). The decomposition of holocellulose in clones of ´Dorskamp´ and ´Blanc du Poitou´ took place at higher temperatures. The mass loss of these two clones was greater than in other cultivars.

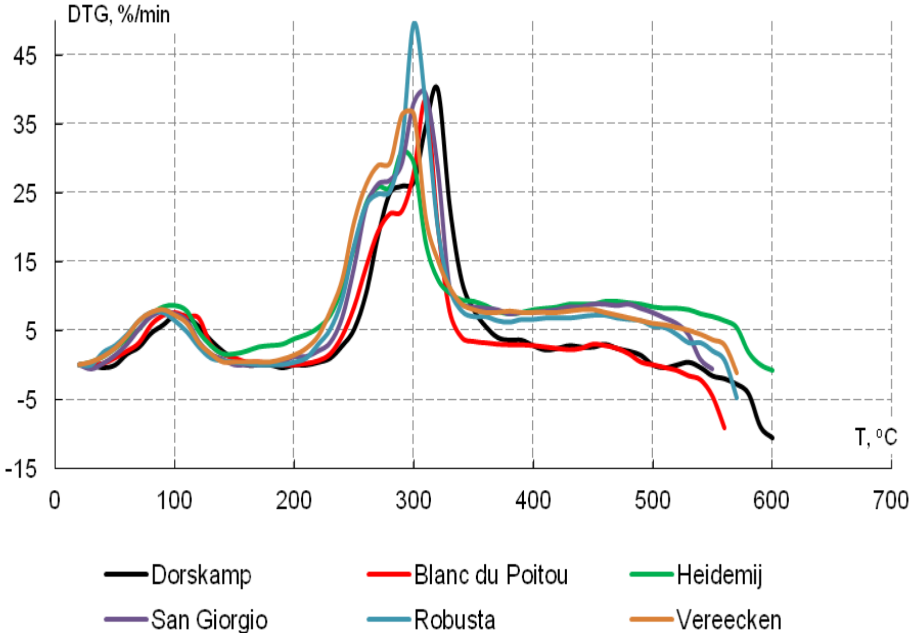

Fig. 3. *DTG curves of poplar wood thermal decomposition*

The highest speed of passing this stage was characteristic of the “Robusta” wood. The slowest process occurred in the wood of ´Heidemij´.

The last stage of thermolysis took place with the decomposition of lignin and the formation of a non-combustible residue. The process was slow, with a relatively constant speed, without pronounced peaks (Table 3 and Figure 3). More complete wood burning was observed for the “Robusta” clone, despite the fact that the share of residual mass of other cultivars was also small, in the range of 4.4-6.2%.

The lowest speed and mass loss were observed in clones of ´Dorskamp´ and ´Blanc du Poitou´ , which indicates a low content of lignin in the wood of these cultivars. The largest mass loss and the proportion of non-combustible residue were characteristic of the ´Vereecken´ clone.

The decomposition stages of holocellulose and lignin were accompanied by exothermic reactions with pronounced thermal effects in the temperature range of 310-520°C.

The activation energy is a good indicator of the thermal stability of wood. The activation energy was determined at the beginning of the process of wood destruction and the subsequent decomposition of the main components. It was found that the smallest amount of energy was required to start the destruction process in the wood of the ´Blanc du Poitou´ and ´Heidemij´ clones, and the largest in the wood of the ´Vereecken´ clone (Table 4). Thus, the lowest thermal stability at the time of destruction of the main components was characteristic of clones ´Heidemij´ and ´Vereecken´, and the greatest - of ´Blanc du Poitou´ and ´San Giorgio´ clones.

Table 4

Activation energy of poplar wood thermal decomposition

Cultivar	**Activation energy [kJ/mol]**	
	Initial	**Main components**
Dorskamp	63.84	66.89
Blanc du Poitou	35.02	69.30
Heidemij	44.44	52.62
San Giorgio	49.19	70.59
Robusta	53.51	57.71
Vereecken	83.65	53.50

At the Pokrov reclamation station, seven clones of fast-growing poplar were studied. Cuttings received from the Boyarka experimental station were planted in phytomeliorated loess-like loam in the spring of 2019 to check for survival. The results of assessing the survival rate of cuttings are shown in Figure 4.

The worst indicators were observed for the clone ´Heidemij´, only 7%. Clones ´Ghoy´ and ´Dorskamp´ showed a high level of survival (47 and 80%, respectively). For the rest of the clones, this index varied in the range of 23-40%.

To evaluate the influence of environmental factors on the thermal behavior of poplar wood, a comparative thermogravimetric analysis was carried out. ´Tardif de Champagne´ poplar clone grown in Boyarka and Pokrov stations was chosen for this aim. Data presented in Table 5 show that wood thermolysis starts at a temperature of 20-30°C and ends at a temperature of 540°C.

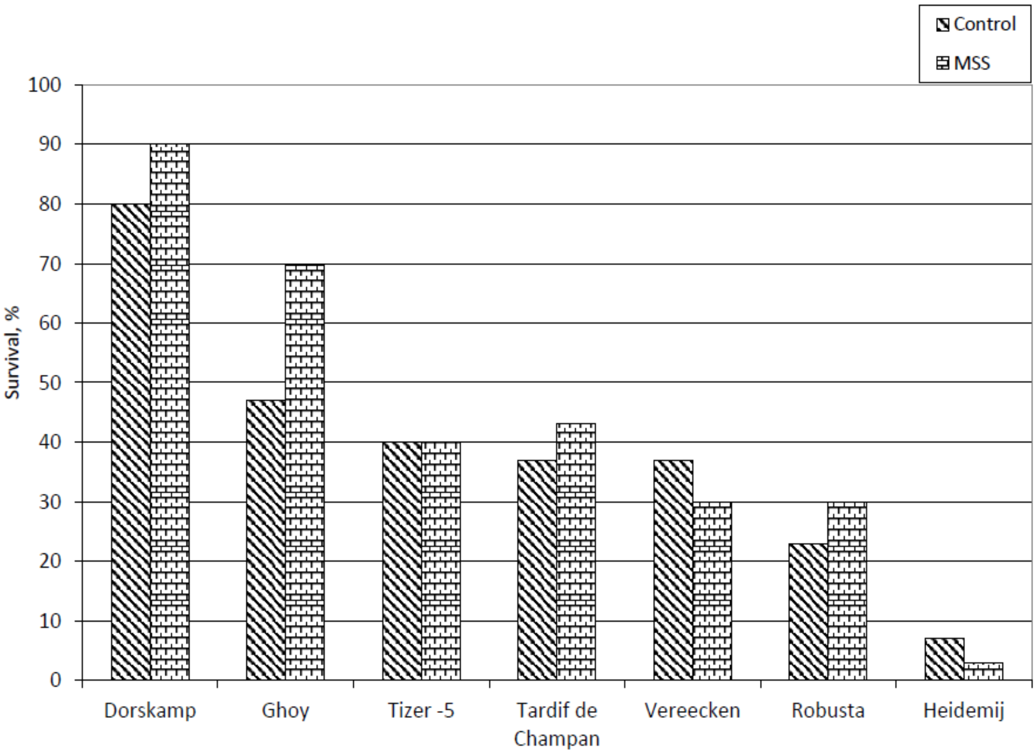

Fig. 4. *Survival of poplar clones in Pokrov station [%]*

Table 5

Thermal characteristics of ´Tardif de Champagne´ poplar clone wood decomposition

Stage	Boyarka station			
	Interval [°C]	Extremum point [°C]	Maximum rate [%/min]	Weight loss [%]
I	30–200	90	13.2	10.0
II, III	200–400	310	44.8	58.8
IV	400–540	470	10.2	23.0
Share of residual mass 8.2%				
Stage	Pokrov station			
	Interval [°C]	Extremum point [°C]	Maximum rate [%/min]	Weight loss [%]
I	20–150	80	16.0	10.0
II, III	150–380	290	34.0	61.2
IV	380–540	430	10.4	23.2
Share of residual mass 5.6 %				

The initial stage of thermal decomposition of clone wood took place against the background of endothermic reactions with weakly expressed thermal effects in the temperature range of 90-120°C (Figure 5b).

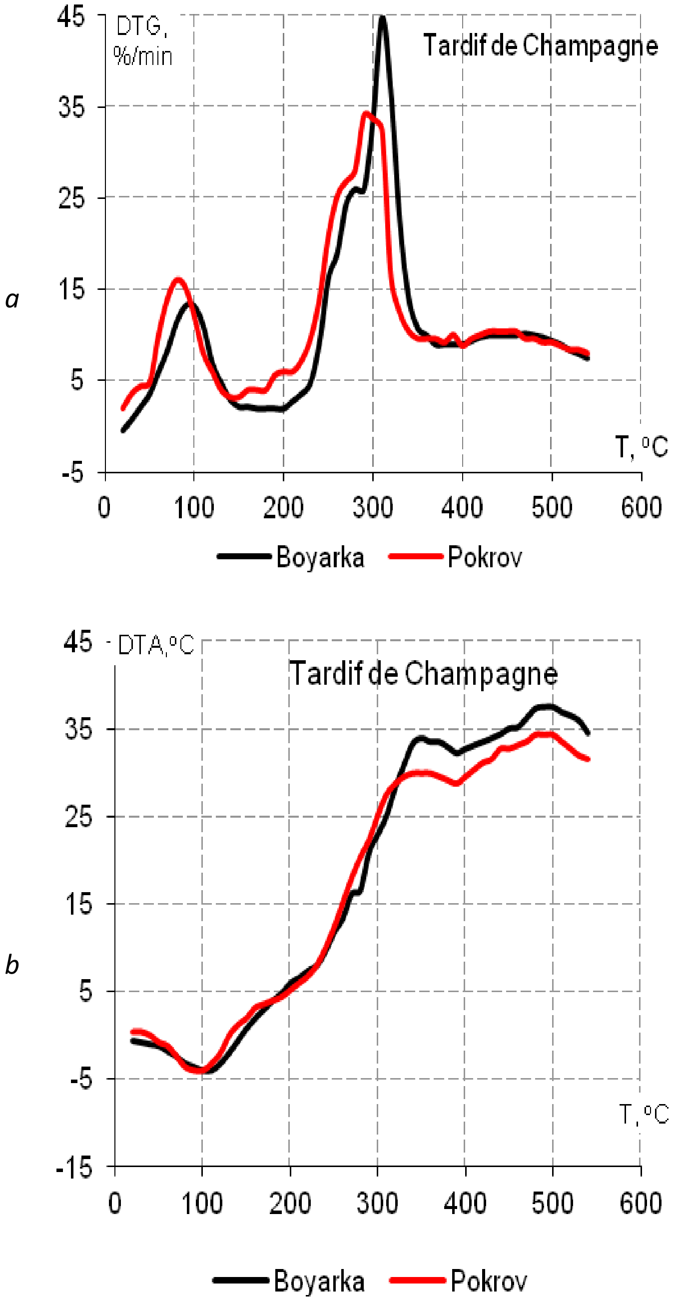

Fig. 5. *DTG and DTA curves of ´Tardif de Champagne´ poplar clone wood thermal destruction in Boyarka and Pokrov stations*

The speed of the process was low. One peak at a temperature of 80-90°C was observed in this range. The loss of mass was 10%. The beginning of destruction of hemicellulose at the stage of decomposition of holocellulose in the clone ´Tardif de Champagne´ shifted to the range of higher temperatures. Therefore, the decay ranges of hemicellulose and cellulose overlap. Only one peak with an extreme point at 310°C (Boyarka) and 290°C (Pokrov) is observed on the thermogravimetric curves (Figure 5a).

The main decomposition of lignin occurred in the temperature range of 300-500°C. The most pronounced exothermic effects are observed in the temperature zone of 300-380°C (cellulose degradation) and 460-500°C (lignin decomposition). Some differences in the thermal characteristics of wood clone grown in different climatic and soil conditions were observed. The evaporation stage of water and volatile compounds in clone grown at the Pokrov reclamation station was shorter. The reaction rate was higher and the initial process took place at lower temperatures. The rate of decomposition of holocellulose was low/lower?

The extreme point was observed at a temperature of 290°C. The rates of lignin decomposition were almost the same in both combustion variants. However, the extreme point in the wood of trees grown at Pokrov land reclamation station shifted to the range of lower temperatures. The content of coke residue was low, and the combustion of wood was more complete.

4. Conclusions

The highest performance indicators of three-year-old wood mass from a single tree were found in cultivars ´Vereecken´ and ´Dorskamp´ in Boyarka research station in Kyiv province. The most intensive growth of 5-year-old unchipped trees was observed in the clones ´Dorskamp´ and “Robusta”. High cutting (at a height of 1.3 m) provided a much larger number of shoots and their large size. The clones ´Ghoy´ , ´Dorskamp´ , and ´San Giorgio had the greatest ability to get shoots. Differences in the thermal characteristics of wood from different cultivars of fast-growing poplar were established. ´Heidemij´ clone wood had the least amount of water and volatile components. The highest content of holocellulose and the lowest content of lignin were typical for clones ´Dorskamp´ and ´Blanc du Poitou´. This allows for considering the wood of these poplars to be of higher quality compared to other cultivars. However, the wood of the ´Robusta´ clone burns most completely. ´Heidemij´ clone wood has the lowest temperature resistance.

The main differences in the wood thermal characteristics of poplar clone ´Tardif de Champagne´ grown under different soil and climate conditions are the changes in the duration of thermolysis stages, the hits in temperature intervals and extreme points, and the changes in mass loss rates. This phenomenon is most likely due to the influence of ecological factors on the complex of extractive substances of wood, which largely determine its thermal behavior.

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