EVALUATION OF THE POSSIBILITY OF ENERGY USE BLACK LOCUST (*Robinia pseudoacacia* L.) DENDROMASS ACQUIRED IN FOREST STANDS GROWING ON CLAY SOILS

OCENA MOŻLIWOŚCI ENERGETYCZNEGO WYKORZYSTANIA DENDROMASY ROBINII AKACJOWEJ (*Robinia pseudoacacia* L.) POZYSKANEJ W DRZEWOSTANACH ROSNĄCYCH NA GLEBACH GLINIASTYCH

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ABSTRACT

In this study, in the assessed capacity using for energy purposes dendromass black locust acquired in three forest stands growing on clay soils. It was found that the test conditions black locust grows well in clay soils very rich, and its timber, in terms of energy use, has a desirable physicochemical properties. Whereas the energy of black locust plantations located on clay soils may be an alternative to gain valuable energy resource.

Keywords: biomass energy, black locust (*Robinia pseudoacacia* L.)

STRESZCZENIE

W pracy, oceniono możliwości wykorzystania na cele energetyczne dendromasy robinii akacjowej pozyskanej w trzech drzewostanach rosnących na glebach gliniastych.

Stwierdzono, że w warunkach badań robinia dobrze przyrasta na mało zasobnych glebach gliniastych, a jej drewno, w aspekcie energetycznego wykorzystania, charakteryzuje się pożądanymi cechami fizykochemicznymi. Natomiast robiniowe plantacje energetyczne lokalizowane na glebach gliniastych mogą być alternatywą na zdobycie cennego surowca energetycznego.

Słowa kluczowe: energia biomasy, robinia akacjowa (*Robinia pseudoacacia* L.)

STRESZCZENIE SZCZEGÓŁOWE

Badania prowadzono w dwóch obiektach na monokulturowych drzewostanach robinii akacjowej. Z wytypowanych drzew próbnych po określeniu ich masy pobrano próby-wyrzynki pni i gałęzi w korze do badań laboratoryjnych, w których określono: wilgotność względną w stanie świeżym, gęstość w stanie świeżym i suchym; wartość opałową w stanie suchym; objętościową wartość opałową drewna suchego w korze jako iloczyn jego gęstości i wartości opałowej.
Stwierdzono, że w warunkach badań robinia dobrze przyrasta na mało zasobnych glebach gliniastych, nierzadko ulegających procesom erozji, preferując cieniste, wilgotne skarpy o wystawie północnej. Przy jej ocenie należy mieć na uwadze, że badane drzewostany zostały założone na stromych, bezglebowych skarpach zwałowiska zewnętrznego, na których wzrost innych roślin energetycznych mógłby być utrudniony. W świetle wyników badań robinię akacjową można polecać do zakładania plantacji energetycznych w trudnych warunkach siedliskowych, w których może być konkurencyjnym gatunkiem dla innych roślin energetycznych (np. wierzby). Należy jednak prowadzić dalsze badania nad możliwościami zwiększenia produkcyjności drewna tego gatunku na plantacjach energetycznych.
Robiniowe plantacje energetyczne lokalizowane na utworach gliniastych mogą być alternatywą na zdobycie cennego surowca energetycznego, równocześnie przynosząc wymierne efekty ekologiczne.

INTRODUCTION

Steadily increasing demand for energy as well as the requirements (Rozporządzenie…, 2008) on environmental protection in the energy sector, leading to increased use of clean, renewable energy sources

(RES). In Poland in 2009 in the total amount of energy produced, renewable energy accounted for less than 9%, in which biomass had participated in approximately 90% (GUS 2010).

Element in regulating the use of biomass for energy purposes is the resource base, which include depends on the size of the crop area and production capacity of soils (Krawiec, 2010). At the same time it is desirable to increase the share of biomass from agricultural and forestry are not (Rozporządzenie…, 2008). In addition, European Parliament and the Council of Europe on the promotion of renewable energy (Dyrektywa, 2009/28/WE) preclude the extraction of biomass for energy purposes from areas of high biodiversity and soils rich in carbon. Also, modern agriculture, in addition to the production and economic objectives, including those related to the production of biomass for energy purposes should fulfill environmental objectives, protecting the natural environment from various types of contamination and risks from agricultural activities. These requirements limit the so area of land which can be used for energy plantations (Stuczyński, 2008).

In the scientific literature, as energy crops, which can be grown on Polish territory, the most frequently mentioned are: willow, poplar, black locust, thornless rose, sida, miscanthus, topinambour and canola (Krawiec, 2010). Some of them, especially in the group of woody plants, willow and poplar, the cultivation require habitats with very good water supply (Lisowski, 2010; Węgorek, 2003a).

Within the agricultural production area are often relatively small enclaves (from a few acres to several hectares) which are unused due to unfavorable conditions for the technical and ecological. Problem is the rational land use industrial wasteland sites and the local exploitation of aggregates, degraded by erosion. Development the forest land farming poses a number of obstacles breeding and organizational (Węgorek, 2003a).

Poor environmental conditions on these lands oblige to fill their crops with small habitat requirements that will protect them and also enable the production of biomass in a longer production cycle than in the classical energy plantations. It is worth mentioning here black locust (*Robinia pseudoacacia* L.), which energy crops in the group calls attention to itself, its biological characteristics, namely: rapid growth, little need for the habitat, relatively low sensitivity to air pollution and ease of cultivation (Węgorek, 2003a). Black locust of successfully grown in the U.S., its home environment as well as in many European countries, even though Romania and Hungary (Huntley, 1990; Redei, et al. 2003). In addition, research in the field of brownfield reclamation and erosion have shown great usefulness of this species in the protection and rescue of such land (Gilewska, 2004; Węgorek, 2003b).

Taking into account the above issues related to ecological and economic conditions of production of biomass for energy purposes, it was research, which aimed to assess the volume of production and the physical properties of black locust wood harvested in stands growing in the clay pieces in terms of energy use for clay soil and harvested one black locust wood.

MATERIALS AND METHODS

The goal of the research is based on two objects located in the Land of Lesser Poland, the Vistula lowlands adjacent mesoregion and Polanyetski Basin. Mesoregion plain Nadwislanska covers a wide valley of the Vistula filled with mostly mud and river sands. Mixed forest habitats dominated moist (27%) and boron mixed fresh (21%). Average biomass potential productivity of forest sites is 4.19 tonnes per hectare in one year. However, on the surface mesoregion Polanyetski Basin are often glacial sands and clays, and the forests here are creating a significant share of large complexes on the sites of boron fresh, fresh mixed coniferous forest and fresh mixed forest. Average biomass potential productivity of these habitats is 4.21 tons per year from 1 ha [Trampler, et al. 1990]. In selecting the objects guided by the presence of monoculture forest stands with the area and the number of trees to allow the separation of representative sample plots and the taking of representative sample trees. Also been taken into account to reproduce the source material of history forest stands. Distinguished three black locust forest stands which were located in two objects:

- No. 1, 2, (in the object Piaseczno), on clay, in the upper slopes dump height of 40 m, the slope angle of about 60-70%, the exhibition - N and S, respectively, afforestation land reclamation stand density in 1225 and 2025 respectively piece per ha, no cuts for farming purposes (without obtaining wood), at age 35;
- No. 3 (in the object Zawidza), on the piece clay in the plain, economic trees from the planting with a density of 410 piece per ha, at the age of 41 years.

In all of the investigated forest stands was determined the test surfaces by the size of 500 m^2, which were soil samples were collected to analyze their wealth, defined the basic characteristics and soil profiles were selected and felled one tree, according to the Bruchwald [1999] recommendations. Abundance of nitrogen was determined by Kowalkowski method (1976), and phosphorus and potassium according to the scale given by the Baule and Fricker (1973). Some trees have an average height and average breast height diameter and habit. Height of a felled tree in the forest stand No. 1 amounted 19.0 m; No. 2 - 18.0 m; No. 3 - 24.5 m, and respectively breast height diameter was 21.0; 18.0; 26.5 cm. Separated from the felled trees trunks and branches in keeping the division on the trunk, branches and thickness classes (≤ 1.0 cm, 1.1-5.0 cm, 5.1-10.0 cm and then every 5 cm) which weighed weight AXIS B30S. As the trunk was treated from the point of felling guide to (5-10 cm above the ground) to a diameter of 5 cm in the cortex (at the end of the upper), the remainder, a thinner part (apex) was attributed to the branch. Productivity was calculated as the average forest stands annual wood increment of dry matter, expressed in $Mg \cdot ha^{-1}$.

The sample trees collected as the sample - slices (representative of the classes and assortments thickness) for further laboratory tests in which specified:

– the relative moisture of fresh timber trunks and branches in bark content with the use of dryer-scale method, by drying the samples in temperature of 105°C in convection dryers;
– the density of timber trunks and branches in bark - both fresh and dry, with the use of weighing and volumetric calculations;
– the calorific value of dry timber trunks and branches in bark - with the use of calorimetry, using KL-12Mn static calorimeter;
– the volumetric calorific value of dry timber in bark, as the product of density and calorific value.

Statistical analysis of the results of the execution took descriptive statistics containing the mean, minimum and maximum number of attempts and the standard deviation.

RESULTS AND DISCUSION

Table 1 lists the basic characteristics of soil profiles under the forest stands and the abundance of soil determined on the basis of the average content of basic nutrients in the layer 0-50 cm. The thickness of 1-5 cm of litter depends on the location of the position in the field and species composition and density of vegetation cover (Table 1). Caries layer of soil under the oldest trees (No. 3) established on agricultural land up to 10 cm, and in forest stands on uncultivated 1-2 cm (Table 1), depending on the position.

On the clay slopes sulfur mine dumping ground (forest stands No. 1-2) in the abundance of soil nutrients is varied. Under the forest stands No. 1 content nitrogen overall and phosphorus at the secondary level, of potassium is a good level. Under the forest stands No. 2 and 3, the nitrogen content is at the secondary level, while phosphorus and potassium at a level insufficient. The content of organic carbon in the soil under forest stands 1 and 3 is at a level above 6 g·kg^{-1}, and under the forest stand at No. 2 4.32 g·kg^{-1} (Table 1).

Table 1. Chosen features of soils

Tabela 1. Wybrane cechy gleb

No. forest stand	Soil	Mulch [cm]	Humus layer [cm]	The nutrient content in [g·kg^{-1}] and abundance of soil				C:N
				$N_{og.}$	P	K	$C_{org.}$	
1	Clay	1	5	0.77 average	0.054 average	0.142 good	6.60	8.57
2		2	6	0.84 average	0.004 insufficient	0.030 insufficient	4.32	5.14
3		3	10	0.78 average	0.007 insufficient	0.025 insufficient	6.05	7.76

Source: author own research

The positions of the soil test ratio of carbon to nitrogen content ranged from slightly more than 5 to less than 9 (Table 1). Such a low value of the ratio (C:N) testifies to the rapid mineralization of organic matter. However with insufficient nitrogen in the soil that trees consume large amounts of this element from the substrate.

The results of studies on timber of black locust in the bark are shown in Table 2.

The study was conducted in tree stands in the same age, growing on clay soils of varying wealth (Table 1). In forest stands 1 and 2 there were no breeding operations (loosening cuts), so the quantity of the various forest stands timber were varied. In forest stands fresh mass of timber in the bark was less than 200 Mg·ha^{-1}. Most fresh timber produced forest stands number 3 occupying a position on the flat - total 218.32 Mg·ha^{-1} (Table 2).

The least produced forest stands number 2 located at the top of a clay slope with southern exposure – 179.94 Mg·ha^{-1}.

Table 2. Productivity and physical qualities black locust timbers in bark

Tabela 2. Produkcyjność i cechy fizyczne drewna robinii akacjowej w korze

Statistical parameter	standNo. forest	Assortment	Fresh mass of trunks and branches in the bark [Mg·ha^{-1}]	Relative moisture of fresh timber [%]	Density of fresh/dry timber [kg·m^{-3}]	Calorific value of dry timber [MJ·kg^{-1}]	Volumetric calorific value of dry timber [GJ·m^{-3}]
Average (The sum of the fresh mass wood)	1	t	173.32	28	813/657	17.86	11.73
		b	27.07	33	748/549	17.80	9.79
	2	t	151.20	28	836/706	18.14	12.80
		b	28.74	35	802/666	17.73	11.81
	3	t	178.76	29	876/732	17.66	12.93
		b	39.56	36	837/697	17.72	12.39
Minimum	1	t	–	26	762/618	17.62	11.16
		b	–	31	566/423	17.28	7.31
	2	t	–	25	807/677	17.95	12.41
		b	–	32	672/637	17.65	12.23
	3	t	–	24	820/700	17.48	11.23
		b	–	24	720/630	17.68	11.32
Maximum	1	t	–	30	840/709	18.16	12.74
		b	–	33	860/670	18.08	12.12
	2	t	–	31	850/730	18.33	13.10
		b	–	38	932/696	17.81	12.39
	3	t	–	42	950/760	17.78	13.50
		b	–	41	920/790	17.98	14.00
Number of trials	1	t	–	4	4	4	4
		b	–	3	3	3	3
	2	t	–	3	3	3	3
		b	–	2	2	2	2
	3	t	–	5	5	5	5
		b	–	4	4	4	4
Standard deviation	1	t	–	1.72	36.82/41.20	0.24	0.73
		b	–	1.05	158.16/123.39	0.43	2.40
	2	t	–	3.15	24.61/26.57	0.19	0.35
		b	–	3.85	183.67/41.68	0.11	0.81
	3	t	–	7.61	48.78/29.50	0.12	0.60
		b	–	7.71	95.35/67.02	0.14	1.14

t – trunk, b – branches
Source: author own research

The ratio of the masses timber forest stands of the richest and the poorest to the average of the forest stands of 1-3 was respectively 110 and 90%.

Under the test conditions are clear differences were observed between the values of fresh timber relative moisture content in the bark trunks and branches of fresh timber relative moisture content in the bark. The question forest stands black locust timber average relative moisture in the bark branches in the fresh state was about 20% greater than the value of this parameter for a tree trunk in the bark. The largest standard deviation of the parameter has been in the forest stand 3, and the smallest in the forest stand 1 (Table 2).

It was also observed slight differences between the values of the density of fresh and dry timber trunks, and the corresponding values of these parameters in the bark branches timber. Average density of fresh timber branches in the bark were 5-8% higher than the value of this parameter for a tree trunk in the bark. In general, the average density of dry wood in the bark of the branches was also lower by 5-8% than the value of this parameter for a tree trunk in the cortex, only wood from forest stand No. 1 relationship had risen to 16%. However, the standard deviation of the parameters in the various stands of the timber was in the case of fresh stems respectively 36.82, 24.61, 48.78, and 158.16 for the wood industry, 183.67, 95.35. For dry wood adequately 41.20, 26.57, 29.50 and 123.39, 41.68, 67.02 (Table 2). The calorific value of dry wood trunks and branches in the cortex in particular forest stands were aligned, and their average values were respectively 17.86, 18.14, 17.66 and 17.8, 17.73, 17.72 [$MJ\cdot kg^{-1}$]. Evidenced by the small standard deviations, which for these parameters in the bark of trunks of wood ranks of 0.12-0.24, and for the wood industry in the cortex – 0,11-0,43. Differences between the values of the density of timber assortments under consideration, have influenced the differentiation of the volumetric heating value. The average value of this parameter for a tree trunk in the bark was respectively 11.73, 12.80, 12.93, and for the timber branches 9.79, 11.81, 12.39 [$GJ\cdot m^{-3}$]. While the standard deviation of these values were approximately 0.73, 0.35, 0.60 (for timber trunks) and 2.40, 0.81, 1.14 (for timber branch) (Table 2).

Research were aimed at, in terms of energy utilization, productivity analysis and physicochemical properties of black locust dendromass acquired in forest stands growing on clay soils. They include the growth of trees, habitat conditions - the nature and richness of the soil. Implementation of such a formulated objective of the research relied so monoculture, the same age forest stands of black locust, where it was possible to conduct studies dendrometric to identify the amount of timber produced by them and to evaluate its physicochemical properties.

Comparative analysis of test results on the production volume of wood in black locust forest stands is difficult because of the very few in the literature of information on timber production in forest stands of comparable age, spacing and planting site conditions. In order to assess the size of timber production in a study conditions, quoted literature data timber mass production in forest stands of varying ages.

According to research Huntley (1990), in the U.S. with 27-year-old forest stands are obtained 126 m^3 of timber per 1 ha. Assuming that the average density of fresh mass in the bark of black locust timber is about 820 $kg \cdot m^{-3}$ (Krzysik, 1974), the volume produced by the timber forest stands at just over 103 $Mg \cdot ha^{-1}$. In the forest habitats in Poland, according to research Pacyniak (1981), 50-year abundance forest stands was slightly over 292 $m^3 \cdot ha^{-1}$, and the mass of timber (as before) - 239.4 $Mg \cdot ha^{-1}$. According to research Rédei, et al. (2003) conducted a five-year plantation of black locust, which was founded in central Hungary, on sandy soils, the productivity of dry wood with planting spacing 1.5×0.3 m was 6.5 $Mg \cdot ha^{-1} \cdot year^{-1}$. While the productivity of the cultivars Jászkiséri and Üllői in the same habitat conditions and the planting spacing of 1.5×1.0 m was respectively 8.0 and 7.3 $Mg \cdot ha^{-1} \cdot year^{-1}$. In conditions own studies in the 35-year old forest stands on the mine waste land mass of fresh wood in the forest stand ranged from 179.94 at the southern slope (stand 2) to 200.39 $Mg \cdot ha^{-1}$ on the northern slope (stand 1), whereas in the a flat mass of fresh wood in 41-year-old stand No. 3 amounted to 218.32 $Mg \cdot ha^{-1}$. In light of above data black locust in the Polish conditions grows well on the works of clay slopes dumps mined and forest economy. However, compared to the plantation black locust in Hungary in conditions of research productivity in forest stands timber is lower. Production of biomass for energy purposes should take place in the plantations with shorter production cycle (Gorzelak, 1999). Currently in Poland among the woody plants grown in energy plantations, mainly of willow (Szczukowski, et al., 2005). In the country substantial yields obtained shrubby willows Szczukowski, et al. (2005) in experiments conducted on brown soil wheat complex average dry matter yield timber willow shrubs in a 4-year cycle of production amounted to 79.31 $Mg \cdot ha^{-1}$. Zajączkowski, et al. (2001) reported that the average yield of dry mass of willow timber in two three-year production cycle in the soil developed from of clay lightweight was 30.92-42.48 $Mg \cdot ha^{-1}$. Results of these can not be compared with the own studies their own because of different habitat characteristics, production conditions and production cycle.

Black locust timber is considered a very good source of energy and is the heaviest wood that can be produced in the plantations of suckers in the natural conditions Polish (Zajączkowski, 2007).

In the study conditions as compared to willow and poplar wood (Krzysik, 1974; Zajączkowski, 2007) black locust timber contains about half the water, the density was nearly 70% more, and calorific value was slightly lower. From the viewpoint of the energy use of black locust timber is advantageous physical properties, and the parameters here are the leading relative moisture and density of timber, which translates into a significant volumetric heating value.

CONCLUSIONS

In conclusion, in a study that black locust grows well in clay soils very rich, often undergoing erosion, preferring shady, moist northern slope of the exhibition. In its assessment should be borne in mind that the investigated forest stands were established on steep slopes soilless external dump, where the growth of other energy crops can be hindered. In light of the results of black locust can recommend the establishment of energy plantations in difficult habitat in which species can be competitive to other energy crops (eg willow). It should be further research into the possibilities to increase the productivity of this species timber for energy plantations.

Energy plantations of black locust located on the works of clay can be an alternative to gain valuable energy resource.

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