Content of chosen macroelements in biomass of Virginia mallow (*Sida hermaphrodita* Rusby)

Zawartość wybranych makroelementów w biomasie ślazowca pensylwańskiego (*Sida hermaphrodita* Rusby)

Joanna SZYSZLAK-BARGŁOWICZ[1]

[1]University of Life Sciences in Lublin, Faculty of Production Engineering, Department of Energy and Vehicles, Poland, correspondence: joanna.szyszlak@up.lublin.pl

Abstract

The aim of the research was assessment of N, P, K, Ca, Mg content in particular parts of Virginia mallow (*Sida hermaphrodita* Rusby), that is leaves, stems and roots, under diversified NPK mineral fertilization. The investigation was conducted on experimental plots sown with Virginia mallow, divided by means of narrow technological paths into two parts characterizing with various spacing of plant rows: plot 1 where spacing between rows of plants was 0.75 m and plot 2 where spacing between the rows was 0.50 m. In both cases the spacing between plants in rows was about 0.4-0.5 m and each experimental plot had an area of 2 700 m^2.
The highest content of investigated macroelements was noted in leaves of Virginia mallow, while the lowest in its roots. Carried out research indicate lack of significant influence of diversified level of fertilization on content of majority of analysed elements in biomass of Virginia mallow. In most cases, only two levels of fertilization significantly influenced level of calcium in plant material. Elevated content of calcium was observed in leaves of Virginia mallow when lower dose of fertilization was used. Moreover, no accumulation of nitrogen in stems and leaves of Virginia mallow was noted, and content of potassium and calcium observed in leaves and stems of Virginia mallow was several times lower than one recommended in order to ensure their care free usage.
Key words: biomass, content of macroelements, cultivation, fertilization, Virginia mallow

Streszczenie

Celem badań było oznaczenie zawartość N, P, K, Ca, Mg w poszczególnych częściach ślazowca pensylwańskiego (*Sida hermaphrodita* Rusby) (liściach, łodygach, korzeniach) przy zróżnicowanym nawożeniu mineralnym (NPK). Badania prowadzono na działkach doświadczalnych obsianych ślazowcem pensylwańskim, podzielonych wąskimi ścieżkami technologicznymi na dwie części, różniące się rozstawem między rzędami roślin: działka 1 o rozstawie między rzędami roślin 0,75 m i działka 2 o rozstawie między rzędami roślin 0,50 m. W obydwu przypadkach odległość między roślinami w rzędach wynosiła 0,4-0,5 m, a każda działka doświadczalna miała powierzchnię 2 700 m^2.
Najwyższą zawartość analizowanych makroelementów stwierdzono w liściach ślazowca pensylwańskiego, natomiast najniższą w korzeniach. Z przeprowadzonych badań wynika brak istotnego wpływu zróżnicowanego poziomu nawożenia na

zawartość większości omawianych składników w biomasie ślazowca pensylwańskiego. Jedynie zastosowane dwa poziomy nawożenia w większości przypadków istotnie wpłynęły na zawartość wapnia w materiale roślinnym. Stwierdzono zwiększoną zawartość wapnia w liściach ślazowca pensylwańskiego przy zastosowaniu niższej dawki nawożenia. Ponadto, nie stwierdzono kumulowania się azotu w łodygach i liściach ślazowca pensylwańskiego a stwierdzona w liściach i łodygach ślazowca pensylwańskiego zawartość potasu i wapnia była wielokrotnie niższa od zalecanej dla zapewnienia ich bezproblemowego użytkowania.
Słowa kluczowe: biomasa, nawożenie, ślazowiec pensylwański, uprawa, zawartość makroelementów

STRESZCZENIE SZCZEGÓŁOWE

Badania prowadzono na działkach doświadczalnych obsianych ślazowcem pensylwańskim (*Sida hermaphrodita* Rusby), podzielonych wąskimi ścieżkami technologicznymi na dwie części różniące się rozstawem między rzędami roślin: działka 1 o rozstawie między rzędami roślin 0,75 m i działka 2 o rozstawie między rzędami roślin 0,50 m. W obydwu przypadkach odległość między roślinami w rzędach wynosiła 0,4-0,5 m, a każda działka doświadczalna miała powierzchnię 2 700 m^2. W pierwszym roku uprawy działki zostały nawiezione saletrą amonową (N 34%), superfosfatem pojedynczym (P 19%) i siarczanem potasu (K 50%) w proporcji N: P: K = 158: 88: 116 = 1,8: 1: 1,3. Nawożenie azotowe wprowadzono w 2 dawkach. W drugim roku uprawy zmniejszono o połowę ilość zastosowanych nawozów i działki doświadczalne nawieziono saletrą amonową (N 34%), superfosfatem pojedynczym (P 19%) i siarczanem potasu (K 50%) w proporcji N: P: K = 79: 44: 58 = 1,8: 1: 1,3. Azot również wprowadzono w 2 dawkach.
Celem badań było oznaczenie zawartość N, P, K, Ca, Mg w poszczególnych częściach ślazowca pensylwańskiego (liściach, łodygach, korzeniach) przy zróżnicowanym nawożeniu mineralnym (NPK).
Z każdej działki doświadczalnej pobrano próbki gleby oraz poszczególnych części roślin ślazowca pensylwańskiego (liście, łodygi i korzenie) i wysuszono je. Analizę fizykochemiczną próbek glebowych i analizę chemiczną próbek roślinnych wykonano w Okręgowej Stacji Chemiczno–Rolniczej w Lublinie. Badania prowadzono przez dwa kolejne lata, w drugim i trzecim roku użytkowania doświadczenia polowego. Przy analizie próbek materiału roślinnego zastosowano metody analityczne: oznaczenie azotu ogólnego PB-70* - metoda destylacyjna, oznaczenie fosforu PB-24* – metoda kolorymetryczna, oznaczenie potasu i wapnia PB-25* – metoda fotometrii płomieniowej, oznaczenie magnezu PB-26* – metoda ASA., (* metoda nieakredytowana).
Najwyższą zawartość analizowanych makroelementów stwierdzono w liściach ślazowca pensylwańskiego, natomiast najniższą w korzeniach. Z przeprowadzonych badań wynika brak istotnego wpływu zróżnicowanego poziomu nawożenia na zawartość większości omawianych składników w biomasie ślazowca pensylwańskiego. Jedynie zastosowane dwa poziomy nawożenia w większości przypadków istotnie wpłynęły na zawartość wapnia w materiale roślinnym. Stwierdzono zwiększoną zawartości wapnia w liściach ślazowca pensylwańskiego przy zastosowaniu niższej dawki nawożenia. Ponadto nie stwierdzono kumulowania się azotu w łodygach i liściach ślazowca pensylwańskiego a stwierdzona w liściach i łodygach ślazowca pensylwańskiego zawartość potasu i wapnia była wielokrotnie niższa od zalecanej dla zapewnienia ich bezproblemowego użytkowania.

Introduction

Necessity to counteract occurring climatic changes forces undertaking actions aimed at limiting emission of greenhouse gasses (Faber 2001). Moreover, constantly increasing demand for energy and increasing prices of crude oil lead to degradation of natural environment and they are a financial burden. Currently energetic safety is of greater importance than ever, food production, improvement of living conditions and improvement of state of the environment are tightly bonded. With that being the background, utilization of biofuels as domestic and renewable energy sources may be an important factor in a process of lowering dependence on import of fossil energetic raw materials and can also stimulate economic development of rural areas (Harsono, Subranto 2013). Availability of fuel is one of key factors affecting market of energetic products for individual users, and what is more, it significantly influences environmental determinants (Kowalski, Lelek 2011). Energetic cultivations are new and at the same time the most diverse group of raw materials, characterizing with probably the highest potential for delivering biomass for energetic purposes. Virginia mallow (*Sida hermaphrodita* Rusby), is often indicated to be among species of plants having high cropping potential (Antonkiewicz 2005, Borkowska, Styk 2006, Gradziuk 2002, Kościk 2007, Kowalczyk-Juśko 2005).

Mineral substance present in biomass plays a significant role in processes of combustion, gasification and pyrolysis. Alkaline metals, sulphur and chloride released during thermal transformation of biomass are the cause of so called high-temperature corrosion (Ściążko et al. 2006). Compounds of calcium and magnesium increase temperature of ash fusibility, while potassium lowers it. Silicon in connection with potassium may lead, in particles of fly ash, to formation of low-melting silicates. These processes are important because of threat related to fouling and slagging of ash on a grate, agglomeration of fluidized bed in fluidised bed burner and deposition of impurities on walls of furnace or heatable surfaces (Rybak 2006).

For recipients of biomass it is not only important that supply of raw material remains constant at a proper level, but also its quality, often bonded with content of various elements. Content of the elements in biomass is affected by genetically conditioned characteristics, which to some degree are modified by environmental conditions such as properties of soil (soil richness, pH), weather conditions (precipitation) as well as agrotechnical treatments - mainly fertilization (Borkowska, Lipiński 2007). Knowledge of content of various elements may be useful when method of biomass processing into energy (pyrolysis, co-combustion or producing solid fuel in form of pellets) is to be chosen (Borkowska, Lipiński 2008). According to Srogi (2007) significant participation of alkaline elements combined with ash content above 5% may have negative effect on a process of pyrolysis. Research conducted by Kowalczyk-Jusko (2008) enabled statement that particular species of plants differ in terms of chemical composition and energetic parameters. Criteria determining introduction of Virginia mallow into the research are its favourable properties in terms of energetic value: low moisture content during harvest, low content of ash and sulphur, high heating value and combustion heat.

Materials and Methods

The investigation was conducted on experimental plots sown with Virginia mallow, divided by means of narrow technological paths into two parts, characterizing with various spacing of plant rows: plot 1 where spacing between rows of plants was 0.75 m and plot 2 where spacing between the rows was 0.50 m. In both cases the spacing between plants in rows was about 0.4-0.5 m and each experimental plot had an area of 2 700 m^2.

Soil on which the experiment was established, according to division of soils into particle size groups and subgroups (BN–78/9180–11) is silty light loam. Content of humus was 2.3%, and content of available forms of major minerals expressed in mg per 100 g of soil was: P –13.6; K – 22.2; Mg – 8.4 and pH 7.4. In the first year of cultivation, the plots were fertilized with ammonium nitrate (N 34%), single superphosphate (P 19%) and potassium sulphate (K 50%) proportion N: P: K = 158: 88: 116 = 1.8: 1: 1.3. Nitrogen fertilizer was introduced in two doses. In the second year of cultivation the amount of fertilizers was lowered by half and the experimental plots were fertilized with ammonium nitrate (N 34%), single superphosphate (P 19%) and potassium sulphate (K 50%) in proportion N: P: K = 79: 44: 58 = 1.8: 1: 1.3. Nitrogen fertilizer was also introduced in two doses.

Assessment of N, P, K, Ca, Mg content in particular parts of Virginia mallow, under diversified NPK mineral fertilization was the aim of the research. Determination of particular elements content in plant samples was conducted in three repetitions. Determination of pH of soil on which Virginia mallow was cultivated has been carried out as well.

From each experimental plot samples of soil as well as particular parts of Virginia mallow plants (leaves, stems and roots) were taken and then dried. Physical-chemical analyses of soil samples and chemical analyses of plant samples were carried out in Chemical Agricultural Station in Lublin. The research was carried out for a period of two subsequent years in a second and third year of conducting plot experiment.

Soil samples were analyses by means of following analytical methods: pH - PN–ISO 10390:1997, determination of phosphorus, potassium and magnesium content KQ/PB–07* (carbonate soils). Determination of particle size distribution PN R–04062:1998, PB–33* areometric method. Humus determination PB-34* – Turin's method. Analysis of plant material: determination of total nitrogen PB - 70* distillation method, determination of phosphorus PB-24* - colorimetric method, determination of potassium and calcium PB-25* – flame photometry method, determination of magnesium PB-26* – ASA method (* non-accredited method).

Results and Discussion

Value of pH of soil on which Virginia mallow plants were cultivated remained similar. In the first year it was 7.33 in case of the first plot and 7.40 for soil sampled from the second plot. In the second year pH was 7.36 and 7.42 for plots 1 and 2 respectively (neutral pH).

Content of analysed elements in leaves, stems and roots of Virginia mallow was presented in tables 1, 2 and 3.

Table 1. Content of N, P, K, Ca and Mg in leaves of Virginia mallow
Tabela 1. Zawartość N, P, K, Ca i Mg w liściach ślazowca pensylwańskiego

Element	Content in the first year of conducting the research (% d.a.m.) fertilization N:P:K = 158:88:116	Content in the second year of conducting the research (% d.a.m.) fertilization N:P:K = 79:44:58

		Value determination			Average	Value determination			Average
Plot 1	N	3.05	3.34	2.5	2.96^{a}	3.17	3.43	2.82	3.14^{a}
	P	0.46	0.41	0.29	0.39^{a}	0.40	0.39	0.29	0.36^{a}
	K	3.48	3.72	3.00	3.40^{a}	3.67	3.41	3.60	3.56^{a}
	Ca	2.88	3.00	3.84	3.24^{a}	4.62	4.41	4.17	4.40^{b}
	Mg	0.26	0.20	0.26	0.24^{a}	0.24	0.25	0.21	0.23^{a}
Plot 2	N	2.67	2.76	2.39	2.61^{a}	3.56	3.04	3.13	3.24^{b}
	P	0.32	0.30	0.26	0.29^{a}	0.33	0.35	0.38	0.35^{a}
	K	3.16	3.68	3.08	3.31^{a}	3.40	3.24	3.56	3.40^{a}
	Ca	3.60	3.42	3.29	2.61^{a}	4.18	4.30	4.36	4.28^{b}
	Mg	0.24	0.20	0.20	0.21^{a}	0.24	0.23	0.20	0.22^{a}

Mean in rows marked with various letters in index mean that significant (α = 0,05) differences between investigated properties were noted

Table 2. Content of N, P, K, Ca and Mg in stems of Virginia mallow
Tabela 2. Zawartość N, P, K, Ca i Mg w łodygach ślazowca pensylwańskiego

		Content in the first year of conducting the research (% d.a.m.) fertilization N:P:K = 158:88:116				Content in the second year of conducting the research (% d.a.m.) fertilization N:P:K = 79:44:58			
	Element	Value determination			Average	Value determination			Average
Plot 1	N	0.46	0.63	0.26	0.45^{a}	0.71	0,65	0.64	0.67^{a}
	P	0.15	0.12	0.08	0.12^{a}	0.08	0.08	0.06	0.07^{a}
	K	1.34	2.00	1.12	1.49^{a}	1.55	1.47	1.29	1.44^{a}
	Ca	0.48	0.55	0.42	0.48^{a}	0.66	0.67	0.76	0.70^{b}
	Mg	0.08	0.06	0.04	0.06^{a}	0.07	0.07	0.05	0.06^{a}
Plot 2	N	0.41	0.41	0.26	0.36^{a}	0.50	0.52	0.45	0.49^{a}
	P	0.08	0.08	0.06	0.07^{a}	0.04	0.04	0.05	0.04^{b}
	K	1.28	1.32	0.92	1.17^{a}	0.95	0.89	0.74	0.86^{a}
	Ca	0.62	0.48	0.62	0.57^{a}	0.63	0.60	0.54	0.59^{a}
	Mg	0.06	0.04	0.04	0.05^{a}	0.06	0.06	0.05	0.06^{a}

Mean in rows marked with various letters in index mean that significant (α = 0,05) differences between investigated properties were noted

Table 3. Content of N, P, K, Ca and Mg in roots of Virginia mallow
Tabela 3. Zawartość N, P, K, Ca i Mg w korzeniach ślazowca pensylwańskiego

		Content in the first year of conducting the research (% d.a.m.) fertilization N:P:K = 158:88:116				Content in the second year of conducting the research (% d.a.m.) fertilization N:P:K = 79:44:58			
	Element	Value determination			Average	Value determination			Average
Plot 1	N	1.04	1.49	0.67	1.07^{a}	1.76	1.92	1.62	1.77^{a}
	P	0.33	0.36	0.33	0.34^{a}	0.31	0.31	0.24	0.29^{a}
	K	2.04	2.36	1.88	2.09^{a}	2.19	2.27	2.37	2.28^{a}
	Ca	0.76	0.81	0.71	0.76^{a}	1.03	1.01	1.14	1.06^{b}
	Mg	0.18	0.20	0.18	0.19^{a}	0.25	0.26	0.22	0.24^{b}

Plot 2	N	1.12	1.52	0.58	1.07^{a}	1.58	1.56	1.72	1.62^{a}
	P	0.34	0.31	0.29	0.31^{a}	0.30	0.29	0.24	0.28^{a}
	K	1.96	2.32	1.90	2.06^{a}	2.62	2.32	2.27	2.40^{a}
	Ca	0.62	0.71	0.64	0.66^{a}	1.08	1.07	0.81	0.99^{a}
	Mg	0.20	0.22	0.16	0.19^{a}	0.24	0.23	0.24	0.24^{a}

Mean in rows marked with various letters in index mean that significant (α = 0,05) differences between investigated properties were noted

Under diversified NPK mineral fertilization no influence of diverse number of plants per area unit on content of investigated elements in leaves, stems and roots of Virginia mallow, was noted. The highest content of investigated macroelements was noted in leaves of Virginia mallow, while the lowest in its roots. Data presented in tables indicate lack of significant influence of diversified level of fertilization on content of majority of analysed elements in biomass of Virginia mallow. In most cases, only two levels of fertilization significantly influenced level of calcium in plant material. Elevated content of calcium was observed in leaves of Virginia mallow when lower dose of fertilization was used. In contrary to results of research of Kalembasa and Wiśniewska (2006), content of nitrogen in stems of Virginia mallow did not increase with increased nitrogen fertilization. Results presented by above mentioned authors indicate that when acquisition of biomass as an energetic raw material is considered, optimal dose of nitrogen was 100 $kg \cdot ha^{-1}$. Nevertheless, no accumulation of nitrogen in stems and leaves of Virginia mallow was noted after increased doses of the nutrient were introduced. It is worth mentioning that Dresler et al. (2011) noted, while observing influence of type of cultivation, fertilization with nitrogen and diversified organic fertilization on content of nitrite nitrogen in soils of eastern Poland, that dose of nitrogen exceeding 121 $kgN \cdot ha^{-1}$ caused significant increase of nitrates in a surface layer of soil. Borkowska and Lipiński (2007) noted that intense nitrogen fertilization did not significantly influenced content of macroelements in Virginia mallow. Moreover, noted by Borkowska and Lipiński (2008) tendency of increase of phosphorus and potassium after introduction of nitrogen in a dose of 100 $kg \cdot ha^{-1}$ was not observed.

When considering energetic utilization of biomass, conclusions elaborated by Fijałkowską and Styszko (2011), on the basis of their research, should be quoted. That is, fertilizer combinations had small, yet significant, effect on willow biomass combustion heat. Rybak (2006), quoting presented in Handbook of Biomass Combustion and Co-Firing (2002), recommended values of elemental compounds content in biofuel, provides advised content of N, K and Ca in fuel (tab. 4). Content of nitrogen in leaves of Virginia mallow exceeded recommended value. Content of potassium and calcium in leaves and stems of Virginia mallow was significantly lower than recommended for their problem-free use. As Kalembasa and Wiśniewska (2006) report, content of nitrogen, potassium and phosphorus in a crop of leaves and stems of Virginia mallow decreases as vegetation season prolongs, what is a typical phenomenon in a course of plant growth and development.

Table 4. Recommended values of elemental compounds content in biofuel required for its problem-free use
Tabela 4. Zalecane wartości składników elementarnych w biopaliwie dla zapewnienia ich bezproblemowego użytkowania (Handbook of Biomass Combustion and Co-Firing 2002)

Compound	Recommended values in fuel (%)	Limited parameter
N	< 0.6	NOx emission
Ca	15-35	Slagging
K	< 7	Slagging, fouling, corrosion

Source: Handbook of Biomass Combustion and Co-Firing 2002
Źródło: Handbook of Biomass Combustion and Co-Firing 2002

Content of analysed elements in solid biofuel depends on its origin and type. In table 5 typical content of N, P, K, Ca and Mg in various types of biomass (Obernberger et al. 2006) and mean, based on obtained research results, content in Virginia mallow stems, which are the main raw-material to be used for energetic purposes, were presented.

Table 5. Typical content of N, P, K, Ca, Mg in various types of biomass
Tabela 5. Typowa zawartość N, P, K, Ca, Mg w różnych rodzajach biomasy

Type of biomass		Concentration (%)				
		N	P	K	Ca	Mg
Wood without bark*	Coniferous wood	0.1	0.006	0.04	0.9	0.015
	Decidous wood	0.1	0.01	0.08	0.12	0.02
Short rotation coppice Willow*		0.5	0.08	0.3	0.5	0.05
Miscanthus (China reed)*		0.7	0.07	0.7	0.2	0.06
Virgin reed canary grass *		1.4	0.17	1.2	0.35	0.13
Strow from wheat, rye, barley*		0.5	0.1	1.0	0.4	0.07
Grains from wheat, rye, barley*		2.0	0.4	0.05	0.05	0.15
Strow from oilseed rape*		0.8	0.1	1.0	1.5	0.07
Grass in general*		1.4	0.3	1.5	0.35	0.17
Wirgina mallow**		0.54	0.075	1.24	0.58	0.06

*Obernberger i in.2006, ** own research
(*Obernberger i in.2006, ** badania własne

Conclusions

Based on carried out research following conclusions were drawn:

Under diversified NPK mineral fertilization no influence of diverse number of plants per area unit on content of investigated elements in leaves, stems and roots of Virginia mallow, was noted.

Diversified fertilization did not alter significantly participation of majority of analysed elements in biomass of Virginia mallow.

Lower dose of fertilization caused decrease of calcium content in leaves of Virginia mallow.

No accumulation of nitrogen in stems and leaves of Virginia mallow was noted.

Content of potassium and calcium observed in leaves and stems of Virginia mallow was several times lower than one recommended in order to ensure their care free usage.

References

Antonkiewicz J., (2005) Potencjał energetyczny ślazowca pensylwańskiego. Aura, 3, 7-9.

Borkowska H., Styk B., (2006) Ślazowiec pensylwański (*Sida hermaphrodita* Rusby), Uprawa i wykorzystanie. WAR, Lublin.

Borkowska H., Lipiński W., (2007) Zawartość wybranych pierwiastków w biomasie kilku gatunków roślin energetycznych. Acta Agrophysica, 10 (2), 287-292.

Borkowska H., Lipiński W., (2008) Porównanie zawartości wybranych pierwiastków w biomasie ślazowca pensylwańskiego uprawianego w różnych warunkach glebowych. Acta Agrophysica, 11(3), 589-595.

Dresler S., Bednarek W., Tkaczyk P., (2011) Nitrate Nitrogen in the Soils of Eastern Poland as Influenced by Type of Crop, Nitrogen Fertilisation and Various Organic Fertilisers, Journal of Central European Agriculture, 12 (2), 367-379. DOI: 10.5513/JCEA01/12.2.924

Faber A., (2001) Emisja gazów cieplarnianych oraz retencjonowanie węgla przez rolnictwo. Fragmenta Agronomica, 4, 102-117.

Fijałkowska D., Styszko L., (2011) Ciepło spalania biomasy wierzbowej. Rocznik Ochrona Środowiska (Annual Set The Environment Protection). Vol. 13, 875-890.

Gradziuk P., (2002) Alternatywne wykorzystanie gruntów rolniczych - przegląd roślin energetycznych. Czysta Energia 10, 24-26.

Handbook of Biomass Combustion and Co-Firing, (2002) Eds. Sjaak van Loo, Jaap Koppejan, Twente University Press.

Harsono S. S., Subranto B., (2013) Land-Use Implications to Energy Balances and Greenhouse Gas Emissions on Biodiesel from Palm Oil Production in Indonesia. Journal of Central European Agriculture, 14 (2), 35-46. DOI: 10.5513/JCEA01/14.2.1231.

Kalembasa S., Wiśniewska B., (2006) Wpływ dawek azotu na plon biomasy ślazowca pensylwańskiego (*Sida hermaphrodita* Rusby) oraz zawartość w niej makroelementów. Acta Agrophysica, 8(1), 127-138.

Kościk B., (2007) Surowce energetyczne pochodzenia rolniczego. Wydawnictwo Naukowe Państwowej Wyższej Szkoły Zawodowej im. ks. Bronisława Markiewicza w Jarosławiu.

Kowalczyk-Juśko A., (2005) Atrakcyjny ślazowiec. Agroenergetyka, 1, 12-14.

Kowalczyk-Juśko A., (2008) Porównanie składu chemicznego i wartości energetycznej biomasy wybranych gatunków roślin. Uprawa roślin energetycznych a wykorzystanie rolniczej przestrzeni produkcyjnej. Materiały XII Konferencji Naukowej IUNiG Puławy, 35-36.

Kowalski Z., Lelek Ł., (2011) Modelowanie rynku biomasy w Małopolsce z uwzględnieniem aspektów prawnych, rynkowych i ekologicznych. Rocznik Ochrona Środowiska (Annual Set The Environment Protection). Vol. 13, 1429-1440.

Obernberger I., Brunner T., Bärnthaler G., (2006) Chemical properities of solid biofuels – significance and impact. Biomass and Bioenergy, 30, 973-982.

Rybak W., (2006) Spalanie i współspalanie biopaliwa stałych. Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław.

Srogi K., (2007) Termiczne wykorzystanie biomasy w procesie pirolizy. Czysta Energia, 1, 21-23.

Ściążko M., Zuwała J., Pronobis M., (2006) Zalety i wady współspalania biomasy w kotłach energetycznych na tle doświadczeń eksploatacyjnych pierwszego roku współspalania biomasy na skalę przemysłową. Energetyka i Ekologia, 6, 207-220.