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PLANT PRODUCTION FOR BIOMASS INTO ENERGY: ECONOMICS AND ENERGY EFFICIENCY VIEW

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Abstract: *The aim of the paper was to determine the influence of the fertilization level on the energy and economics efficiency of the production technologies of selected crops processed into bioethanol or biogas. There were investigated the following crops: rye, triticale, wheat, sugar beets, maize, sorghum, reed canarygrass and Virginia fanpetals. In the energetic efficiency the Energy Return on Energy Investment index (EroEI) was used. Apart from the ERoEI ratio, the Net Energy Value (NEV) ratio was also used. In the economics efficiency attitude, the Gross Margin (GM) was determined.The investigations proved that in general, the production technologies of crops where the lowest levels of nitrogen fertilization were applied proved to have the highest energetic efficiency. The highest economic efficiency was characterized by the production of corn for biogas. In the case of the production of bioethanol (all plants), ratios were on the verge of profitability or the lack of it showed.The analysis proved that the efficiency of the technologies of production of the crops to be processed into biogas is several times higher than the energetic efficiency of the technologies of production of the crops to be processed into bioethanol.*

Keywords: *biomass, energy consumption, bioethanol, biogas, economics efficiency, energy efficiency*

Introduction

At the time of the energy crisis there are a number of studies on the use of biomass for energetic purposes conducted around the world (Biofuels in EU 2006; Biofuels Progress Report 2006; EEA Briefing 2005). Therefore, it is necessary to conduct research aimed at the evaluation of the energetic and economic efficiency of the technologies related with the production of biomass for energetic purposes (Faaij 2006; Roszkowski 2008).

This issue was undertaken as part of the research project "*The Development of a Species Index and Optimization of Production Technologies for Selected Energy Crops*". It is a five-year research project numbered POIG.01.03.01-00-132/08-00, financed by the European Regional Development Fund as part of the Operational Programme 'Innovative Economy'. The project is implemented in the years 2009-2015.

Many tasks are carried out in the project. Some of them are the analysis of the energy and economics efficiency of the proposed technologies of production of selected crops for energetic purposes.

According to the current prices, the production of presently best-known liquid fuels such as bioethanol or rape oil esters is about twice as expensive as the costs of production of mineral fuels (Dobek et al. 2010). Although at present the costs of production of biofuels are high, there are a lot of advantages resulting from the processing of biomass into energy. Some of them are:

- limited emission of toxic compounds,
- reduced greenhouse effect,
- biodegradability.

Apart from cost accounting energy efficiency costing is an important element in the assessment of production of biofuels. The advantage of energy costing is its independence of price relations, which enables a comparison of findings in different research centres. Therefore, one of the tasks in the project is to make 'An Analysis of the Energy Efficiency of the Proposed Technologies of Production of Selected Crops Grown for Energetic Purposes'.

Aim and scope of the research

A wide range of factors which may influence the effectiveness of production of plants for energetic purposes was analysed in the project. These factors include:

- cultivar traits,
- the degree of nitrogen fertilisation,
- soil type,
- regionalisation of crops,
- applied production technologies and others.

One of the partial aims of the research was to determine the influence of the degree of fertilisation on the energy and economics efficiency of the technologies of production of selected crops processed into biofuels or biogas. These issues are presented in this paper.The advantage of energy costing is its independence of price relations, which enables a comparison of findings in different research centres.

Methods

The project involved experimental field investigations on selected cereal cultivars, sugar beets, maize, sorghum and Virginia fanpetals in order to develop optimal (model) technologies to produce high quality raw material for the production of liquid and gas energy.

The assessment of the energy and economics efficiency of the technologies of production of selected plants processed into bioethanol will show the results concerning sugar beets, maize, triticale and rye the other hand, into biogas – maize, sorghum and Virginia fanpetals. Depending on the plant investigated and allowing for fertilisation requirements the following levels of nitrogen fertilisation were assumed in the research: for cereals and Virginia fanpetals : 40 N, 80 N and 120 N, for maize, sugar beets and sorghum: 80 N, 120 N and 160 N.

As far as maize is concerned, it will enable an additional comparative analysis with a division into diversified use of the plant – for bioethanol or biogas.

As far as biomass is concerned, indexing methods with numerical ratios between outlay made and effects achieved in the entire or partial manufacturing cycle will be used in the comparisons and assessments of energetic usefulness. In order to assess products with the characteristics of energy carriers or fuels, including various forms of biomass, the Energy Return on Energy Investment index (EroEI), also known as the Energy Return on Investment (ERoI), will be used and calculated according to the following formula (1) (Wójcicki 2005):

$$\text{ERoEI (ERoI)} = E_{out} / E_{in} \qquad (1)$$

where:

E_{out} - energy gained (useful)

E_{in} - energy intake, energy input

Apart from the ERoEI ratio, the Net Energy Value (NEV) ratio is also used in the assessment of the energetic efficiency of the product. The ratio is defined as the difference between the amount of energy gained (E_{out}) and the amount of energy consumed to make the product (E_{in}).

The methodology of assessment of the energy gained (E_{out}).

As far as biogas is concerned, its calorific value depends on the content of methane (CH_4), whose calorific value is 39.7 MJ/m^3 (Oleszkiewicz 1999). In the laboratory investigations we determined the content of methane in the biogas produced as a result of fermentation of silages. The silages were made from maize grown at the three aforementioned levels of nitrogen fertilisation. Then the result per 1 ha of the plantation was calculated.

As far as bioethanol is concerned, in the laboratory investigations the ethanol yield ratios were calculated – the number of litres gained from 100 kg of raw material. The calorific value of ethanol was assumed to be 21.5 MJ/l (Górski et al. 2008). Having taken the yield volume into consideration, the result per 1 ha of the plantation was calculated.

The methodology of assessment of the energy intake (E_{in}).

In order to assess the energy intake in the production of biofuel we used the computational method developed at the Institute for Building, Mechanisation and Electrification in Agriculture (IBMER) (Anuszewski 1987) and by Mokrzycki (2005) and Richards (2000). In general, two components of the outlay can be listed. The first concerns the outlay related to the production of the raw material (E_{inp}), whereas the other one concerns the outlay related to the raw material processing (E_{int}). Thus, the general formula for determination of the energy input into the production of biofuel looks as follows (2):

$$Ein = \Sigma E_{inp} + \Sigma E_{int} \qquad (2)$$

where:

E_{in} - as in formula (1),

ΣE_{inp} – total input of energy for the production of plant raw material,

ΣE_{int} – total input energy for the processing of plant raw material into biofuel.

Due to the substantive scope of the project, as far as the energy intake is concerned, this paper will assess the first element related to the production of raw material and supplying it to the place where it will be processed into biofuel.

The total energy related to the production of plant raw material is composed of four basic streams of energy. It is calculated according to the following formula (3):

$$\Sigma Einp = \Sigma Emat + \Sigma Eagr + \Sigma Epal + \Sigma Er \qquad (3)$$

where:

Einp – as in formula (2) [MJ·ha–1];

$\Sigma Emat$ – total energy input from the applied materials* and raw materials [MJ·ha–1];

$\Sigma Eagr$ – total energy input from mechanized working operations [MJ·ha–1];

$\Sigma Epal$ – total energy input from the fuel consumed in working operations [MJ·ha–1];

ΣEr – total energy input from human labour [MJ·ha–1].

*seeds, fertilizers, pesticides, etc.

In the economics efficiency attitude, the gross margin was determined as follows:

$$GM_{nP} = R_{nP} - DC_{nP} \qquad (4)$$

where:

GM_{nP} – Gross Margin of n-plant

R_{nP} – Revenue of n-plant

DC_{nP} – Direct Costs of n-plant

Table 1. The biogas efficiency from the production of maize, sorghum and Virginia fanpetals for silage at different levels of nitrogen fertilisation.

Nitrogen fertilisation level	Yield fresh weight [t/ha]	Biogas [m³/t f.w.]	Biogas [m³/ha]	CH_4 content [%]	CH_4 amount [m³/ha]	Energy gained Eout [MJ/ha]
Maize 80N	43.83	315.33	13821.06	62.00	8569.06	340191.53
Maize 120N	47.23	304.00	14357.92	58.00	8327.59	330605.47
Maize 160N	51.50	204.00	10506.00	54.00	5673.24	225227.63
Sorghum 80N	58.18	175.15	10190.00	60.00	6114.00	242725.80
Sorghum 120N	68.20	163.11	11124.00	58.00	6451.92	256141.22
Sorghum 160N	71.80	170.79	12263.00	57.00	6989.91	277499.43
Virginia fanpetals 40N*	34.23	337.15	11540.64	54.00	6231.95	247408.34
Virginia fanpetals 80N*	37.65	323.19	12168.10	40.00	4867.24	193229.48
Virginia fanpetals 120N*	41.42	246.05	10191.39	34.00	3465.07	137563.40

**I+II swath of Virginia fanpetals*
Source: Authors' calculations.

Findings

As a result of the investigations the volume of energy gained (Eout) from individual plants was assessed.

Table 1 shows the results referring to maize, sorghum and Virginia fanpetals silage for biogas. The table presents the yield obtained, the amount of biogas gained, including the content of methane and the energetic efficiency per 1 ha, depending on the three levels of nitrogen fertilisation.

The highest biogas efficiency per ha was gained from the medium level of fertilisation, i.e. 120 N from the production of maize 14357.92 m3/ha. On the other hand, as far as the methane gain is concerned, which results in the amount of energy gained, the highest efficiency was obtained at the lowest level of nitrogen fertilisation, i.e. 80N – 340191.53 MJ/ha. The same relation was in the case of production of Virginia fanpetals. Quite different results were in the case of sorghum production. Both the highest biogas efficiency per ha and the highest amount of energy gained per ha were gained from the highest level of fertilisation, i.e. 160 N.

Table 2 shows the results for the plants grown for bioethanol. The results include: the yield gained, ethanol efficiency per weight unit of the raw material and per farmland area unit, and the energetic efficiency per 1 ha, depending on the three levels of nitrogen fertilisation.

As results from the data presented in Table 2, the highest amount of energy can be gained from the production of sugar beets, where the fertilisation level is 160 N. It is four times more than the amount gained from cereal production and it is two times more than the amount of energy gained from maize production.

Table 2. The efficiency of bioethanol produced from the selected plants at different levels of nitrogen fertilisation.

Plant/Nitrogen fertilisation level	Yield		Ethanol efficiency		Energy gained E_{out}
	t/ha	dt/ha	l/dt	l/ha	MJ/ha
rye / 40N	4.21	42.10	31.80	1338.78	28783.77
rye / 80N	4.63	46.30	31.60	1463.08	31456.22
rye / 120N	4.52	45.20	31.80	1437.36	30903.24
triticale / 40N	4.55	45.50	31.80	1446.90	31108.35
triticale / 80N	4.78	47.80	33.40	1596.52	34325.18
triticale / 120N	5.06	50.60	34.80	1760.88	37858.92
maize / 80N	8.15	81.50	33.00	2689.50	57824.25
maize / 120N	9.02	90.20	27.20	2453.44	52748.96
maize / 160N	9.23	92.30	32.20	2972.06	63899.29
sugar beets / 80 N	45.80	458.00	9.47	4335.73	93218.27
sugar beets / 120 N	56.76	567.60	10.00	5676.00	122034.00
sugar beets / 160 N	59.89	598.90	9.73	5829.29	125329.81

Source: Authors' calculations.

Table 3. Energy input from the production of maize, sorghum and Virginia fanpetals silage for biogas at different levels of nitrogen fertilisation.

Plant/Nitrogen fertilisation level	E_{mat} fertilisers MJ / ha	E_{mat} others MJ / ha	E_{agr} MJ / ha	E_{pal} MJ / ha	E_r MJ / ha	E_{inp} MJ / ha
Biogas:						
Maize 80N	8242.00	1380.00	2962.73	24451.00	1233.67	38269.40
Maize 120N	11322.00	1380.00	3115.66	26912.74	1346.56	44076.96
Maize 160N	14402.00	1380.00	3238.11	28704.69	1452.73	49177.53
Sorghum 80N	8242.00	1120.00	2343.54	10479.00	504.00	22688.54
Sorghum 120N	11322.00	1120.00	2545.52	11285.00	546.00	26818.52
Sorghum 160N	14402.00	1120.00	2783.12	11975.00	588.00	30868.12
Virginia fanpetals 40N*	5054.00	1290.00	2980.66	12662.12	695.10	22681.88
Virginia fanpetals 80N*	8380.00	1290.00	3156.80	14437.50	777.00	28041.30
Virginia fanpetals 120N*	11690.00	1290.00	3275.90	15750.00	823.20	32829.10

**I+II swath of Virginia fanpetals*
Source: Authors' calculations.

As far as the levels of fertilisation are concerned, for sugar beets the difference in the energy efficiency between the highest and the lowest level of nitrogen fertilisation is 33.5%, but the difference between the highest and the medium level is only 2.9%.

As far as maize is concerned, the lowest energy efficiency was gained from the medium level of fertilisation (120 N) and it was lower than the lowest nitrogen level and the highest nitrogen level by 15.1% and 21.8%, respectively.

As far as cereals are concerned, the lowest fluctuations in the energetic efficiency could be observed in rye. The difference between the highest efficiency (80 N) and the lowest efficiency (40 N) was 8.6%. As far as triticale is concerned, the difference reached 23.2%, but the highest energy efficiency was gained from the highest level of fertilisation (120 N).

It is also interesting to see the comparison of the energy gained from maize depending on the farming technology – grain or silage. This comparison definitely points to the advantage of the silage technology, where about six times more energy was gained than from the for grain technology.

The energy intake (Ein) is the other aspect of the energy balance. As was earlier shown in the methodology, this publication will present the amount of accumulated energy related with the raw material production and transport to the place of processing (Einp). Tables 3 and 4 show the results of investigations into this matter. The volumes of four basic streams of energy were calculated for each of the plants under investigation, allowing for the level of nitrogen fertilisation. In view of the fact that the level of nitrogen fertilisation was the chief factor differentiating the technologies for a particular

Table 4. Energy input from the production of seeds of selected plants for bioethanol at different levels of nitrogen fertilisation.

Plant/Nitrogen fertilisation level	E_{mat} fertilisers MJ / ha	E_{mat} others MJ / ha	E_{agr} MJ / ha	E_{pal} MJ / ha	E_r MJ / ha	E_{inp} MJ / ha
Bioethanol:						
maize / 80 N	8132.00	1220.00	2714.41	18235.35	765.20	31066.96
maize / 120 N	11296.00	1220.00	2680.12	19720.81	799.90	35716.83
maize / 160 N	14367.00	1220.00	2760.35	21318.49	830.51	40496.35
rye / 40 N	5054.00	2302.00	2442.24	8058.89	640.85	18497.98
rye / 80 N	8380.00	2659.00	2502.61	8622.27	638.02	22801.90
rye / 120 N	11690.00	2928.00	2522.68	8802.41	658.43	26601.52
triticale / 40 N	5054.00	2663.00	2492.30	8460.01	692.54	19361.85
triticale / 80 N	8380.00	3024.00	2558.53	9039.20	676.11	23677.84
triticale / 120 N	11690.00	3401.00	2436.35	9083.90	686.90	27298.15
sugar beets / 80 N	8132.00	890.00	6924.03	26877.45	1837.10	44660.58
sugar beets / 120 N	11366.00	1010.00	7036.27	29314.08	2001.46	50727.81
sugar beets / 160 N	14967.00	892.00	7203.56	31005.92	2133.19	56201.67

Source: Authors' calculations.

Table 5. The energy efficiency of selected plants produced for biogas depending on the level of nitrogen fertilisation.

Plant/Nitrogen fertilisation level **Biogas:**	E_{out} MJ / ha	E_{inp} MJ / ha	ERoEI	NEV MJ / ha
Maize 80N	340191.53	38269.40	8.89	301922.13
Maize 120N	330605.47	44076.96	7.50	286528.51
Maize 160N	225227.63	49177.53	4.58	176050.10
Sorghum 80N	242725.80	22688.54	10.70	220037.26
Sorghum 120N	256141.22	26818.52	9.55	229322.70
Sorghum 160N	277499.43	30868.12	8.99	246631.31
Virginia fanpetals 40N*	247408.34	22681.88	10.91	224726.46
Virginia fanpetals 80N*	193229.48	28041.30	6.89	165188.18
Virginia fanpetals 120N*	137563.40	32829.10	4.19	104734.30

**I+II swath of Virginia fanpetals*
Source: Authors' calculations.

plant, the stream of energy related with fertilisation was enhanced in the stream of accumulated energy related with materials and raw materials.

Upon the analysis of the data presented in Table 3 it is noticeable that the technologies with the highest level of nitrogen fertilisation (160 N) are characterised by the highest energy consumption – nearly 50 GJ/ha in case of maize, around 31 GJ/ha in case of sorghum and around 33 GJ/ha in case of Virginia fanpetals (120N) . In the case of maize this energy consumption is 28.5% higher than in the technology with the fertilisation level 80 N and it is 13.4% higher than in the technology with the fertilisation level 120 N. In the structure of energy streams the highest consumption is related with the stream of fuel consumed (Epal) and it makes between 58% and 64% of the total energy consumption. The works related with the preparation and transport of silage were the dominant outlay in this stream. The same trend is also confirmed by a Pepliński study (2014).

Generally, the same relation is observed also in two other plants. But in comparison with maize, both in sorghum and Virginia fanpetals, total energy input from the fuel consumed and total energy input from the human labour are lower around 50% than in case of maize.

The data presented in Table 4 concern the energy input from technology of production of selected plants for bioethanol. As results from the analysis of the data, the technologies of production of sugar beets are the most energy-consuming: 44.6 GJ/ha for the level of 80 N, up to 56.2 GJ/ha for the level of 160 N. The difference between the highest and lowest level of energy consumption is 25%. The dominant energy stream is the stream of fuel consumed (Epal), which ranges from 55% to 60% of total energy consumption. The works related with the harvesting and transport of raw materials were the dominant outlay in this stream. Apart from that, in comparison with the other plants, the technologies of production of sugar beets were found to involve about three times higher outlay related with the energy consumption of the machines and tools applied and with the amount of human labour.

As far as cereals are concerned – rye and triticale – the energy consumption ratios are at similar levels. However, depending on the levels of nitrogen fertilisation, it is possible to observe bigger differences in energy consumption between the technologies than in the case of sugar beets or maize. The difference in energy consumption between the technology with the lowest level of nitrogen fertilisation and the technology with the highest level of nitrogen fertilisation ranges from 41% (triticale) to 43% (rye). The differentiating factor was the level of nitrogen fertilisation.

The analysis of the production of maize for bioethanol reveals that dependences in the structure of energy streams are similar to those in the technologies of cereal production, but there is not such a considerable difference in the total energy consumption. The difference in energy consumption between the technology with the lowest level of nitrogen fertilisation and the technology with the highest level of nitrogen fertilisation is 28.5%. The energy consumption of the technology with maize produced for bioethanol is about 10-15 GJ/ha lower than in the technology of production of sugar beets.

The aim of the final stage of the research was to determine the energy efficiency of the technologies of production of crops for biofuels, depending on the level of nitrogen fertilisation. As results from the data shown in Tables 5 and 6, the highest ERoEI (Energy Return on Energy Investment) ratio could be observed in the technologies of plants produced for biogas. The ratio ranges from 4.19, in the production of Virginia fanpetals where the level of nitrogen fertilisation is120 N, up to 10.91 – the highest efficiency, which is achieved at the lowest level of nitrogen fertilisation, i.e. 40 N. The similar ratio, at the lowest level, is observed in the case of sorghum. Relatively, the lowest ratio was observed in the case of production of maize (from 4.58 up to 8.89) but these technologies were characterised by the highest NEV (Net Energy Value) ratio, i.e. from 176.1 GJ/ha up to 301.9 GJ/ha and it was around 20% higher than in other plants.

As results from the comparative analysis of the technologies of production of the crops to be processed into bioethanol (tab.6), the energetic efficiency of these technologies is several times lower than the efficiency of the technologies of processing the crops into biogas. The ERoEI ratio ranged from 1.16 (the rye technology/120 N) to 2.41 (the sugar beets technology/120 N). The technologies with the lowest levels of nitrogen fertilisation proved to be the most energetically efficient. The technology of production of sugar beets was an exception. In this case the highest efficiency was obtained at the medium level of nitrogen fertilisation, i.e. 120 N.

Table 6. The energy efficiency of selected plants produced for bioethanol depending on the level of nitrogen fertilisation.

Plant/Nitrogen fertilisation level	E_{out} MJ / ha	E_{inp} MJ / ha	ERoEI	NEV MJ / ha
Bioethanol:				
maize / 80 N	57824.25	31066.96	1.86	26757.29
maize / 120 N	52748.96	35716.83	1.48	17032.13
maize / 160 N	63899.29	40496.35	1.58	23402.94
rye / 40 N	28783.77	18497.98	1.56	10285.79
rye / 80 N	31456.22	22801.90	1.38	8654.32
rye / 120 N	30903.24	26601.52	1.16	4301.72
triticale / 40 N	31108.35	19361.85	1.61	11746.50
triticale / 80 N	34325.18	23677.84	1.45	10647.34
triticale / 120 N	37858.92	27298.15	1.39	10560.77
sugar beets / 80 N	93218.27	44660.58	2.09	48557.69
sugar beets / 120 N	122034.00	50727.81	2.41	71306.19
sugar beets / 160 N	125329.81	56201.67	2.23	69128.14

Source: Authors' calculations.

Table 7. The economics efficiency of selected plants produced for biogas depending on the level of nitrogen fertilisation.

Plant/Nitrogen fertilisation level	Direct costs EUR/ha	Revenue EUR/ha	Gross Margin EUR/ha
Biogas:			
Maize 80N	951	2004	1054
Maize 120N	1010	2158	1149
Maize 160N	1075	2330	1255
Sorghum 80N	616	1614	998
Sorghum 120N	651	1891	1241
Sorghum 160N	690	1991	1302
Virginia fanpetals 40N*	587	685	98
Virginia fanpetals 80N*	623	753	130
Virginia fanpetals 120N*	663	828	165

**I+II swath of Virginia fanpetals*
Source: Authors' calculations.

The gross margin analysis (Table 7) showed that in the case of production of plants for processing into the biogas the highest GM was characterized by sorghum (1302 EUR/ha) and maize (1255 EUR/ha). Given the fact, that the production of sorghum was also marked by the highest energy efficiency, it would prefer this plant in the production for processing into the biogas.

Table 8. The economics efficiency of selected plants produced for bioethanol depending on the level of nitrogen fertilisation.

Plant/Nitrogen fertilisation level	Direct costs EUR/ha	Revenue EUR/ha	Gross Margin EUR/ha
Bioethanol:			
maize / 80 N	752	961	209
maize / 120 N	795	1032	238
maize / 160 N	842	1112	269
rye / 40 N	450	668	218
rye / 80 N	420	711	291
rye / 120 N	453	758	305
triticale / 40 N	544	974	430
triticale / 80 N	602	1047	445
triticale / 120 N	642	1127	486
sugar beets / 80 N	1466	2932	1466
sugar beets / 120 N	1596	3201	1605
sugar beets / 160 N	1710	3497	1786

Source: Authors' calculations.

However, in the case of production plants for processing into bioethanol the highest rate of GM was characterized by the production of sugar beets. The level of the indicator was from 4 to 7 times higher compared to the other plants. However, despite of a favorable gross margin rate in the production of sugar beet, but the low rate of energy efficiency, it is not recommended to use this plant for the production for processing into biofuels.

Conclusions

1. The investigations proved that in general, the technologies of crop production at the lowest levels of nitrogen fertilisation have the highest energetic efficiency (except for sugar beets, where the highest efficiency was achieved at the medium level of fertilisation).
2. The comparative analysis proved that the efficiency of crop production for processing into biogas is several times higher than the energetic efficiency of the production for bioethanol.
3. The energetic efficiency of maize produced for biogas is several times higher than the efficiency of this crop produced for bioethanol.
4. The analysis of economic efficiency showed that the highest gross margin was achieved in the production of sorghum which also has the highest energy efficiency and should be preferred in the production of biogas.

5. This will enable improvement of the quality parameters of the raw material, increase the volume of production (yield of ethyl alcohol and biogas), improve the technologies of production of selected energy crops, reduce their production costs and rationalise logistic processes.

References

Anuszewski R., Pawlak J., Wójcicki Z. 1979. Energochłonność produkcji rolniczej. Metodyka badań energochłonności produkcji surowców żywnościowych. Wydaw. IBMER, Warszawa. s. 23-28.

Biofuels in the European Union. 2006. A vision for 2030 and beyond. Final draft of the Biofuels Research Advisory Council.

Biofuels Progress Report. 2006. Communication from the Commission to the Council and the European Parliament. Commission of the European Communities, Brussels, [9.1.2007] COM 845 final.

Dobek T.K., Dobek M., Sarec O. 2010. Ocena efektywności ekonomicznej i energetycznej produkcji pszenicy ozimej i rzepaku ozimego wykorzystanych do produkcji biopaliw. Inżynieria Rolnicza, 1:161-168.

EEA Briefing. 2005. How much biomass can Europe use without harming the environment? European Environment Agency. ISSN 1830-2246. http://www.energybulletin.net/

Faaij A.P.C. 2006. Bio-energy in Europe: changing technology choices. Energy Policy 34:322-342.

Górski K., Olszewski W., Lotko W. 2008. Alkohole i estry jako paliwa dla silników o zapłonie samoczynnym. Czasopismo Techniczne. Wyd. Politechniki Krakowskiej, z.7-M:13-24.

Mokrzycki E. 2005. Podstawy gospodarki surowcami energetycznymi. Wydawnictwo Naukowo-Dydaktyczne AGH Kraków. ISBN 83-89388-23-5

Muzalewski A. 2009. Koszty eksploatacji maszyn. Wydaw. IBMER, Nr 24. Warszawa. ISBN 978-83-806-31-4.

Oleszkiewicz J., 1999. Eksploatacja składowisk odpadów. Wyd. LP s.c. Kraków.

Pepliński B., 2014. Analiza kosztów logistyki w produkcji kiszonek na biogaz. Logistyka 6:13629-13637.

Richards I.R. 2000. Energy balances in the growth of oilseed rape for biodiesel and of wheat for bioethanol. Levington Agriculture Report. BABFO. s. 9-38.

Roszkowski A. 2008. Energia a rolnictwo (kryzys energetyczny – efektywność – rolnictwo). Inżynieria Rolnicza 4:25-35

Wójcicki Z. 2000. Wyposażenie i nakłady materiałowo energetyczne w rozwojowych gospodarstwach rolniczych. Wydaw. IBMER. Warszawa. ISBN 83-86264-62-4.

Wójcicki Z. 2005. Metodyczne problemy badania energochłonności produkcji rolniczej. Problemy Inżynierii Rolniczej, 1(47): 5-12.