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EMISSIONS FROM THE PRODUCTION OF CHEMICAL FERTILISERS AND FUEL CONSUMPTION IN VARIOUS TECHNOLOGIES OF ENERGY CROPS CULTIVATION*

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Abstract. The paper presents the results of a study on the impact of the cultivation of crops which may serve as a substrate for a biogas plant on the atmosphere. Subjects addressed in the study cover a range of issues related to greenhouse gas (GHG) emissions from this area of agricultural activity. The amounts of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emitted to the atmosphere in the selected cultivation technologies of beet, maize for silage and grasses were calculated. Emissions of GHG from chemical fertiliser production corresponding to the quantities used in the individual technologies were analysed, and amounts of the emitted above-mentioned pollutants originating from diesel fuel used during agricultural treatments conducted with the use of agricultural machinery were calculated. Emission values were expressed in equivalent units – E_{CO_2eq}. The study demonstrated that technologies which result in the highest quantities of emission are maize cultivation technologies – the average value for the study crops is 1 428 490.56 g ha^{-1} CO_{2eq}. The lowest level of pollutants in the form of emitted greenhouse gases originates from grass cultivation and its average value is 904 661.28 g ha^{-1} CO_{2eq}.

Keywords: greenhouse gas, emission, production of chemical fertilisers, fuel consumption, energy crops

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INTRODUCTION

Nowadays, global warming is one of the most important issues on a global scale. The results of these changes can be irreversible. More and more attention is given to find possibilities and means to lower the speed of changes occurring in the natural environment. Climate policy is discussed not only among environmentalists, but also scientists conducting research within various fields of science. Numerous conferences which concern the current condition of the environment, the existing policy in the field of climate protection, and resulting hazards, are dedicated to this issue. A search for solutions aimed at meeting obligations arising from the memberships contracts with the European Union is conducted. As a country, Poland is contractually bound to comply with the accepted principles of natural resources management, and to achieve established targets in the field of limitation of the greenhouse effect process which is mostly caused by the emission of greenhouse gases (GHG) such as CO_2, CH_4 and N_2O to the atmosphere.

From 2016, agriculture is a part of economic sectors whose emission of greenhouse gases is analysed in reports on the European Union level.

Greenhouse gases (GHG) contribute to the greenhouse effect by absorbing infrared radiation, or by the retention of heat in the atmosphere. They also include water vapour (H_2O) and ozone (O_3). These gases occur naturally in the atmosphere. The increasing concentration of GHG in the atmosphere is mainly caused by combustion of fossil fuels, industrialisation processes and changes in land use. This is associated with more and more intensive methods of cultivation (deforestation – more than 90% of emission resulting from changes in land use). These changes result in an increase in GHG concentration and belong among the major causes of anthropogenic climate change, known as global warming (Singel 2014).

Estimates from studies indicate an increase in air temperature in relation to the period of 150 years ago by approx. 0.5-0.7°C. The air temperature of the 1990-2000 decade was the highest not only within the period of 150 years, but also probably in the whole last millennium (Poskrobko *et al.* 2007). The Intergovernmental Panel on Climate Change (IPCC 2011) argues that the lack of control on emissions of greenhouse gases will cause an increase in mean temperatures in the world by over 6°C, compared to the preindustrial era till the end of this century (Singel 2014).

The emission of pollutants is associated with various fields and forms of human activity, mostly in the area of industry. Chemical compounds entering the atmosphere undergo numerous changes, react with other compounds, which sometimes leads to the formation of new chemical compounds whose negative environmental impact is sometimes greater than the harmfulness of the primary pollutants (Banaś and Solarski 2010).

METHODS

Basing on in situ field investigations, process sheets for the crops of sugar beet, maize for silage and grasses were developed. For the study, we selected 11 technologies for beet cultivation (B1-B11), 12 technologies for maize for silage cultivation (M1-M12), and 10 technologies for grass cultivation (G1-G10). A database was prepared for each of the analysed technologies, containing the following information: quantity of applied chemical fertilisers and amount of fuel used in individual stages of cultivation for all performed agricultural treatments in the selected technologies for the cultivation of sugar beet, maize for silage and grass crops. Each technology was characterised in terms of quantity of pure nitrogen (N), phosphorous (P) and potassium (K) which were delivered to plants during the growing season. These calculations were necessary in the subsequent stage of the study to calculate the amount of emission for CO_2, CH_4 and N_2O originating from the production of a pure ingredient contained in fertilisers used for a particular crop. Among the emissions generated in the production chain of raw materials for biogas plants, carbon dioxide, methane and nitrous oxide were analysed. In order to calculate the emissions from the production of fertilisers, emission factors of individual greenhouse gases for the production of pure N, P and K were used. These are values which determine emission quantities expressed in grams, attributable to the production of 1 kg of a pure ingredient (Tab. 1).

Table 1. Greenhouse gas emissions from the production of 1 kg of N, P, K in chemical fertilisers

Nutrient	Emission of GHG (g kg^{-1})		
	CO_2	CH_4	N_2O
N	2 351	0.24	15.1
P	923	0.04	0.03
K	553	0.03	0.04

Source: own elaboration based on Hansen *et al*. (2006) as cited in Pasyniuk (2010)

The analyses included the amounts of fuel which were needed for agricultural treatments in each of the cultivation technologies. For the calculation of CO_2, CH_4 and N_2O emission from fuel consumption, emission factors based on the combustion of 1 litre of fuel were applied (Tab. 2).

Table 2. Emission values for CO_2, N_2O and CH_4 originating from 1 litre of diesel fuel

Type of pollutant	Emission value for 1 l of diesel fuel (g l^{-1})
CO_2	2 730
N_2O	0.1
CH_4	0.13

Source: own elaboration based on Meyer-Aurich *et al*. 2006

In order to enable a comparison between greenhouse emissions, an equivalent unit, so-called global warming potential (GWP), was calculated. It expresses the amount of carbon kilograms which, during 100 years, produces the same effect of global warming as 1 kg of the analysed greenhouse gas. For the calculation of emissions expressed in CO_2 equivalent, guidelines contained in the Act were used (Dziennik Ustaw 2014). Values of the global warming potential for the most popular greenhouse gases are presented in Table 3.

Table 3. Global warming potential of gases

	Conversion factor to CO_2 equivalent
CO_2	1
N_2O	296
CH_4	23

Source: own elaboration based on Annex II.3. Point 5 of Methodology Section of the Act of 21st March 2014, item 457

According to the assumptions comprised in the methodology, a formula was developed for the calculation of greenhouse emissions (expressed in CO_2 equivalents) resulting from the production of chemical fertilisers and from fuel consumption at the individual stages of the applied technologies used for energy crops cultivation:

$$E_{CO_2eq} = E_{CO_2} \cdot 1 + E_{N_2O} \cdot 296 + E_{CH_4} \cdot 23 \qquad (1)$$

where: E_{CO_2eq} – emission value in CO_2 equivalents; E_{CO_2} – emission value for CO_2; E_{N_2O} – emission value for N_2O; E_{CH_4} – emission value for CH_4.

RESULTS

Based on the assumptions comprised in the methodology, emission values of CO_2, CH_4 and N_2O for individual crop technologies were calculated. The results of the calculations are presented in Tables 4-6.

Table 4. Emission of CO_2, CH_4 and N_2O from the production of fertilisers applied in various technologies of beet cultivation

Technology	Amount of NPK from chemical fertilisers ($kg\ ha^{-1}$)			Amount of pure ingredients from chemical fertilisers ($kg\ ha^{-1}$)			Emission from production of pure components of chemical fertilisers ($g\ kg^{-1}$)									Total ($g\ ha^{-1}$)		
							N			P			K					
	N	P_2O_5	K_2O	N	P	K	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
B1	122	0	93	122	0	77.19	286 822	0	1 165.57	112 606	0	2.32	42 686.07	2.32	3.09	442 114.07	2.32	1 170.97
B2	174	364	0	174	160.16	0	409 074	38.44	0	160 602	6.41	0	0	0	0	569 676	44.84	0
B3	119	46	30	119	20.24	24.9	279 769	4.86	375.99	109 837	0.81	0.75	13769.7	0.75	1.00	403 375.7	6.41	377.73
B4	50	138	138	50	60.72	114.54	117 550	14.57	1 729.55	46 150	2.43	3.44	63 340.62	3.44	4.58	227 040.62	20.44	1 737.57
B5	121	50	108	121	22	89.64	284 471	5.28	1 353.56	111 683	0.88	2.69	49 570.92	2.69	3.59	445 724.92	8.85	1 359.84
B6	163	90	135	163	39.6	112.05	383 213	9.5	1 691.96	150 449	1.58	3.36	61 963.65	3.36	4.48	595 625.65	14.45	1 699.8
B7	56	92	120	56	40.48	99.6	131 656	9.72	1 503.96	51 688	1.62	2.99	55 078.8	2.99	3.98	238 422.8	14.32	1 510.93
B8	98	60	60	98	26.4	49.8	230 398	6.34	751.98	90 454	1.06	1.49	27 539.4	1.49	1.99	348 391.4	8.89	755.47
B9	81	60	60	81	26.4	49.8	190 431	6.34	751.98	74 763	1.06	1.49	27 539.4	1.49	1.99	292 733.4	8.89	755.47
B10	30	60	60	30	26.4	49.8	70 530	6.34	751.98	27 690	1.06	1.49	27 539.4	1.49	1.99	125 759.4	8.89	755.47
B11	90	92	180	90	40.48	149.4	211 590	9.72	2 255.94	83 070	1.62	4.48	82 618.2	4.48	5.98	377 278.2	15.82	2 266.4

Source: own results

Table 5. Emission of CO_2, CH_4 and N_2O from the production of fertilisers applied in various technologies of maize cultivation

Technology	Amount of NPK from chemical fertilisers ($kg\ ha^{-1}$)			Amount of pure ingredients from chemical fertilisers ($kg\ ha^{-1}$)			Emission from production of pure components of chemical fertilisers ($g\ kg^{-1}$)									Total ($g\ ha^{-1}$)		
							N			P			K					
	N	P_2O_5	K_2O	N	P	K	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
M1	197	92	180	197	40.48	149.4	463 147	9.72	2 255.94	181 831	1.62	4.48	82 618.2	4.48	5.98	727 596.2	15.82	2 266.4
M2	181	60	160	181	26.4	132.8	425 531	6.34	2 005.28	167 063	1.06	3.98	73 438.4	3.98	5.31	666 032.4	11.38	2 014.58
M3	148.4	96	144	148.4	42.24	119.52	348 888.4	10.14	1 804.75	136 973.2	1.69	3.59	66 094.56	3.59	4.78	551 956.16	15.41	1 813.12
M4	132	58	68	132	25.52	56.44	310 332	6.12	852.24	121 836	1.02	1.69	31 211.32	1.69	2.26	463 379.32	8.84	856.19
M5	138	60	114	138	26.4	94.62	324 438	6.34	1 428.76	127 374	1.06	2.84	52 324.86	2.84	3.78	504 136.86	10.23	1 435.39
M6	75.6	0	0	75.6	0	0	177 735.6	0	0	69 778.8	0	0	0	0	0	247 514.4	0	0
M7	115	28	25	115	12.32	20.75	270 365	2.96	313.33	106 145	0.49	0.62	11 474.75	0.62	0.83	387 984.75	4.07	314.78
M8	173	24	24	173	10.56	19.92	406 723	2.53	300.79	159 679	0.42	0.6	11 015.76	0.6	0.8	577 417.76	3.55	302.19
M9	115	0	0	115	0	0	270 365	0	0	106 145	0	0	0	0	0	376 510	0	0
M10	78.2	0	276	78.2	0	229.08	183 848.2	0	3 459.11	72 178.6	0	6.87	126 681.24	6.87	9.16	382 708.04	6.87	3 475.14
M11	75.4	0	0	75.4	0	0	177 265.4	0	0	69 594.2	0	0	0	0	0	246 859.6	0	0
M12	80	203	0	80	89.32	0	188 080	21.44	0	73 840	3.57	0	0	0	0	261 920	25.01	0

Source: own results

Table 6. Emission of CO_2, CH_4 and N_2O from the production of fertilisers applied in various technologies of grass cultivation

Technology	Amount of NPK from chemical fertilisers (kg ha^{-1})			Amount of pure ingredients from chemical fertilisers (kg ha^{-1})			Emission from production of pure components of chemical fertilisers (g kg^{-1})									Total (g ha^{-1})		
							N			P			K					
	N	P_2O_5	K_2O	N	P	K	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O
G1	223	213	0	223	93.72	0	524 273	22.49	0	205 829	3.75	0	0	0	0	730 102	26.24	0
G2	46	0	0	46	0	0	108 146	0	0	42 458	0	0	0	0	0	150 604	0	0
G3	48	96	96	48	42.24	79.68	112 848	10.14	1,203.17	44 304	1.69	2.39	44 063.04	2.39	3.19	201 215.04	14.22	1 208.75
G4	84	30	40	84	13.2	33.2	197 484	3.17	501.32	77 532	0.53	1	18 359.6	1	1.33	293 375.6	4.69	503.64
G5	116	40	60	116	17.6	49.8	272 716	4.22	751.98	107 068	0.7	1.49	27 539.4	1.49	1.99	407 323.4	6.42	755.47
G6	123	0	0	123	0	0	289 173	0	0	113 529	0	0	0	0	0	402 702	0	0
G7	57	0	0	57	0	0	134 007	0	0	52 611	0	0	0	0	0	186 618	0	0
G8	129	0	0	129	0	0	303 279	0	0	119 067	0	0	0	0	0	422 346	0	0
G9	255	0	0	255	0	0	599 505	0	0	235 365	0	0	0	0	0	834 870	0	0
G10	97	0	0	97	0	0	228047	0	0	89 531	0	0	0	0	0	317 578	0	0

Source: own results

The results of calculation of the emission originating from the production of chemical fertilisers, for the amounts of fertilisers used in each technology of cultivation of individual plant species, respectively, were expressed in equivalent units and included in the following Table 7.

Table 7. Emission resulting from the production of chemical fertilisers used in different cultivation technologies of beet, maize for silage and grasses, expressed in CO_2 equivalents

Technology	Plantation acreage (ha)	Emission (CO_{2eq} g ha^{-1})
B1	3.24	788 775.13
B2	6	570 707.43
B3	2	515 332.19
B4	2.5	741 831.94
B5	2	848 440.74
B6	5	1 099 098.34
B7	2.5	685 988.09
B8	4	572 213.71
B9	6	516 555.71
B10	6.4	349 581.71
B11	5.7	1 048 495.79
M1	13	1 398 813.79
M2	13	1 262 608.54
M3	4.5	1 088 993.7
M4	2	717 016.27
M5	2	929 246.24
M6	3.5	247 514.4
M7	2	481 252.55
M8	3.4	666 946.69
M9	3.25	376 510
M10	10	1 411 508.61
M11	8	246 859.6
M12	5	262 495.22
G1	14.5	730 705.56
G2	3.25	150 604
G3	19	559 330.74
G4	15	442 562.14
G5	4	631 089.04
G6	7.9	402 702
G7	2.1	186 618
G8	10	422 346
G9	5	834 870
G10	8.25	317 578

Source: own results

The highest average value of emission originating from the production of the applied quantities of chemical fertilisers was recorded for maize – 757 480.47 g ha^{-1} CO_{2eq}, a slightly lower value was calculated for beet – 703 365.53 g ha^{-1} CO_{2eq}, while the lowest average value of GHG emitted during the production of chemical fertilisers applied during the growing season was found for grass – 467 840,55 g ha^{-1} CO_{2eq}.

Another factor, a direct source of greenhouse gas emission to the atmosphere, which was investigated was the quantity of greenhouse gases originating from the combustion of diesel fuel, emitted to the atmosphere. Tables 8-10 present the results of GHG emission originating from the combustion of diesel fuel, expressed in CO_2 equivalents, for the technology of cultivation of beet, maize for silage and grasses, respectively. For the studied technologies of beet cultivation, the average emission level resulting from fuel consumption amounted to 703 355.41 g ha^{-1} CO_{2eq}.

Table 8. Emission of CO_2, CH_4 and N_2O originating from fuel used in different technologies of beet cultivation

Technology	Consumed amount of fuel (l ha^{-1})	Emission from consumed fuel (g l^{-1})			Emission from consumed fuel (CO_{2eq} g ha^{-1})
		CO_2	CH_4	N_2O	
B1	232	633 360	30.16	23.2	640 920.88
B2	155.7	425 061	20.24	15.57	430 135.26
B3	396.8	1 083 264	51.58	39.68	1 096 195.71
B4	277.7	758 121	36.1	27.77	767 171.24
B5	251.3	686 049	32.67	25.13	694 238.87
B6	312.4	852 852	40.61	31.24	863 033.12
B7	265.9	725 907	34.57	26.59	734 572.68
B8	134.5	367 185	17.49	13.45	371 568.36
B9	306.7	837 291	39.87	30.67	847 286.35
B10	256.6	700 518	33.36	25.66	708 880.59
B11	211	576 030	27.43	21.1	582 906.49

Source: own results

In the case of technologies of cultivation of maize for silage, the average level of emissions originating from fuel consumption amounted to 671 010.09 g ha^{-1} CO_{2eq}. In the case of technologies of grass cultivation, the average emission value amounted to 436 820.73 g ha^{-1} CO_{2eq}, which was the lowest value among the studied technologies of crop production.

Table 9. Emission of CO_2, CH_4 and N_2O originating from fuel used in different technologies of maize cultivation

Technology	Consumed amount of fuel (l ha^{-1})	Emission from consumed fuel (g l^{-1})			Emission from consumed fuel (CO_{2eq} g ha^{-1})
		CO_2	CH_4	N_2O	
M1	123.5	337 155	16.06	12.35	341 179.87
M2	152.9	417 417	19.88	15.29	422 400.01
M3	116.2	317 226	15.11	11.62	321 012.96
M4	184.5	503 685	23.99	18.45	509 697.86
M5	116.5	318 045	15.15	11.65	321 841.74
M6	418.6	1 142 778	54.42	41.86	1 156 420.17
M7	343	936 390	44.59	34.3	947 568.37
M8	323.5	883 155	42.06	32.35	893 697.87
M9	250	682 500	32.5	25	690 647.5
M10	389	1 061 970	50.57	38.9	1 074 647.51
M11	368	1 004 640	47.84	36.8	1 016 633.12
M12	129	352 170	16.77	12.9	356 374.11

Source: own results

Table 10. Emission of CO_2, CH_4 and N_2O originating from fuel used in different technologies of grass cultivation

Technology	Consumed amount of fuel (l ha^{-1})	Emission from consumed fuel (g l^{-1})			Emission from consumed fuel (CO_{2eq} g ha^{-1})
		CO_2	CH_4	N_2O	
G1	125.1	341 523	16.26	12.51	345 600.01
G2	150.3	410 319	19.54	15.03	415 217.28
G3	135.7	370 461	17.64	13.57	374 883.46
G4	85.4	233 142	11.1	8.54	235 925.19
G5	210	573 300	27.3	21	580 143.9
G6	189	515 970	24.57	18.9	522 129.51
G7	217	592 410	28.21	21.7	599 482.03
G8	176	480 480	22.88	17.6	486 215.84
G9	171	466 830	22.23	17.1	472 402.89
G10	121.7	332 241	15.82	12.17	336 207.2

Source: own results

Total emissions resulting from the production of chemical fertilisers and from the consumption of fuel used in beet cultivation technologies ranged from 943 782.07 gha^{-1} CO_{2eq} to 1 962 131.46 g ha^{-1} CO_{2eq}, for the cultivation technologies of maize for silage the values ranged from 618 869.33 g ha^{-1} CO_{2eq} to 2 486 156.12 g ha^{-1} CO_{2eq}, and for the cultivation technologies of grass the lowest value of total emission from these two sources amounted to 565 821.28 g ha^{-1} CO_{2eq} while the highest one was 1 307 272.89 g ha^{-1} CO_{2eq}.

The result of the study in the for of graphs are presented in Figures 1 and 2.

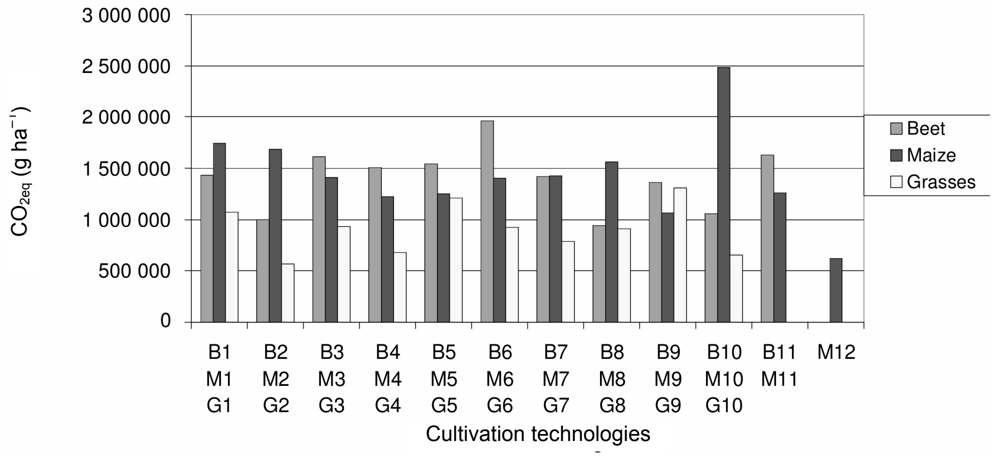

Fig. 1. Total emission resulting from the production of chemical fertilisers and consumption of fuel in individual technologies of beet, maize and grass cultivation, expressed in CO_2 equivalents

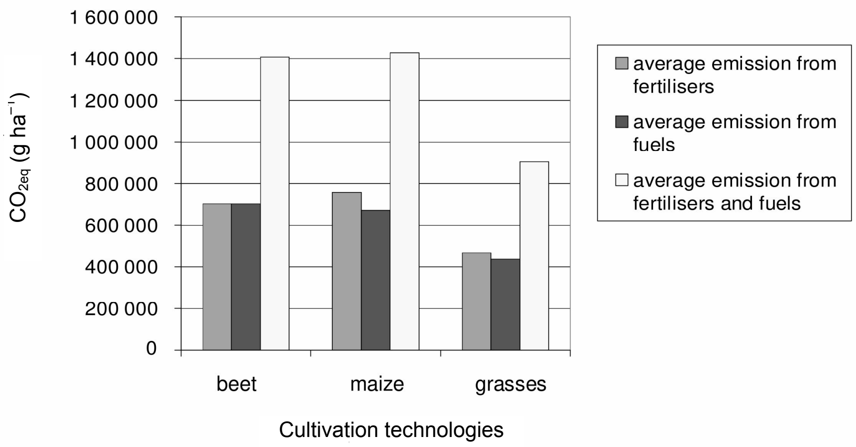

Fig. 2. Average emissions resulting from the production of applied fertilisers and consumed fuel for the studied crops of beet, maize and grasses

SUMMARY AND CONCLUSIONS

A consequence of the requirements established by the Directive 2009/28/EC is the search for possible limitations of GHG emission at every stage of production of crops intended for energy purposes (Jarosz and Faber 2015). From 2017, producers of energy from renewable sources will be obliged to demonstrate a reduction in GHG emission by minimally 50% in relation to gasoline in biofuel life cycle (Directive 2009).

The emission and concentration of greenhouse gases (CO_2, N_2O, CH_4) in the atmosphere are also influenced by emission from agricultural lands. Emission level from soils is dependent not only on the amount of the introduced nitrogen fertiliser, but above all on the intensity of nitrification and denitrification processes (Sapek 2002) which occur with varying intensity depending on climatic conditions, soil properties, as well as agricultural and plant-care treatments, conducted within the chain of plant-based raw material production (Nyćkowiak *et al*. 2012).

Based on the conducted study the following conclusions were formulated:

1. Technologies which are characterised by the lowest average values of greenhouse gas emission to the atmosphere, resulting from the production of chemical fertilisers used during the production and from the consumption of fuel during treatments with the use of agricultural machinery are grass cultivation technologies. The total average emission from the studied sources was 904 661.28 g ha^{-1} CO_{2eq}.

2. The highest average emission value – 1 428 490.56 g ha^{-1} CO_{2eq} – was recorded for the technologies of maize cultivation, and the average emission value for beet cultivation – 1 406 720.94 g ha^{-1} CO_{2eq} – was only slightly below this value.

As in the case of studies of the influence of growing technology on the soil, it is recommended to continue analyses of the emission of GHG from growing technologies, including the emissions generated during the remaining agricultural treatments (natural fertilisation, use of plant protection products), depending on the present soil processes in different systems of plant cultivation (Konieczna and Roman 2013), as well as other sources associated with the production and application of materials and raw materials at individual stages of plant cultivation (Hryniewicz and Grzybek 2016).

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EMISJE Z PRODUKCJI NAWOZÓW SZTUCZNYCH I ZUŻYCIA PALIW W RÓŻNYCH TECHNOLOGIACH UPRAW ROŚLIN ENERGETYCZNYCH

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Streszczenie: W artykule przedstawiono wyniki badań wpływu na atmosferę upraw roślin, które mogą posłużyć jako substrat do biogazowi. Zagadnienia poruszone w opracowaniu obejmują zakres problematyki związanej z emisją gazów cieplarnianych (GHG) z tego obszaru działalności rolniczej. Obliczono ilość emisji dwutlenku węgla (CO_2), metanu (CH_4) i podtlenku azotu (N_2O) jakie zostały wyemitowane do atmosfery w wybranych technologiach uprawy buraków, kukurydzy na kiszonkę i traw. Rozważono emisje GHG z produkcji nawozów sztucznych odpowiadające ilościom zastosowanym w poszczególnych technologiach oraz wyliczone zostały ilości wyemitowanych wyżej wymienionych zanieczyszczeń pochodzących z zużytego oleju napędowego podczas przeprowadzonych za pomocą maszyn rolniczych zabiegów agrotechnicznych. Wartości emisji wyrażono w jednostce ekwiwalentnej – E_{CO2eq}. Badania wykazały, że technologiami, z których pochodzą największe ilości emisji są technologie uprawy kukurydzy – średnia wartość z badanych upraw to 1 428 490,56 CO_{2eq}. Najniższy poziom zanieczyszczeń emitowanych gazów cieplarnianych pochodzi z upraw traw i wynosi średnio 904 661,28 CO_{2eq}.

Słowa kluczowe: gaz cieplarniany, produkcja nawozów sztucznych, zużycie paliwa, rośliny energetyczne