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Characteristic of carbon dioxide absorption by cereals in Poland and China

Introduction

In according to the Intergovernmental Panel for Climate Change (IPCC) reports (IPCC 2007, 2013) one of the greatest threats for the human civilization is climate change caused by the increased concentrations of greenhouse gases in the atmosphere, the most important of which is carbon dioxide emitted from the combustion of fossil fuels and cement production (E_{ff}). Its emission is constantly growing, since the beginning of Industrial Revolution. Especially intensive increase of carbon dioxide emission is observed since the 1960s. The second important source of CO_2 emission are the changes in the land use (E_{LUC}) (Table 1).

The emitted carbon dioxide is absorbed in the photosynthesis process by plants and dissolved in oceans and sea water (Table 2). The remaining part is accumulated in the atmosphere, leading to an increase its concentration (Table 3).

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Table 1. Annual mean global emission of carbon dioxide in particular decades (Le Quere et al. 2018)

Tabela 1. Średnia roczna światowa emisja dwutlenku węgla w poszczególnych dekadach

	From combustion and cement production (E_{ff}) ($GtCO_2$/yr)	From land use change (E_{LUC}) ($GtCO_2$/yr)
1960–1969	11.4	5.1
1970–1979	17.2	4.0
1980–1989	20.2	4.4
1990–1999	23.1	4.8
2000–2009	28.6	4.4
2007–2016	34.5	4.8
2016	36.3	4.8
2017	37.0	–

Table 2. Annual global mean net sink of carbon dioxide in ocean water and terrestrial ecosystems in particular decades (Le Quere et al. 2018)

Tabela 2. Średnia roczna wartość netto globalnego pochłaniania dwutlenku węgla w wodach oceanicznych i ekosystemach lądowych w poszczególnych dekadach

	Ocean sink (S_{ocean}) $GtCO_2$/yr	Terrestrial sink (S_{land}) $GtCO_2$/yr
1960–1969	3.7	5.1
1970–1979	4.8	8.8
1980–1989	6.2	7.3
1990–1999	7.0	9.2
2000–2009	7.7	10.6
2007–2016	8.8	11.0
2016	9.5	9.9

Terrestrial ecosystems, on the one hand, absorb CO_2 and transform it into biomass in the photosynthesis process. On the other hand, they emit the CO_2 produced in respiration and dead biomass decomposition processes. These are the two most important fluxes of CO_2.

Plants absorb globally approximately 123 Gt C/yr in the photosynthesis process and at the same time emit 118.7 Gt C/yr in the respiration and biomass decomposition processes (IPCC 2013). The previously published sources report slightly different absorption and emission values, e.g. the report of Intergovernmental Panel for Climate Change (IPCC 2007)

Table 3. Annual global accumulation of CO_2 in the atmosphere in particular decades (Le Quéré et al. 2018) and its concentration in the atmosphere (ESRL data)

Tabela 3. Światowa akumulacja i stężenie CO_2 w atmosferze w poszczególnych dekadach

	Growth of the amount of CO_2 in the atmosphere Gt (CO_2/yr)	Concentration in atmosphere (ppm)
1960–1969	6.2	317–319
1970–1979	10.3	325–338
1980–1989	12.5	339–353
1990–1999	11.4	354–368
2000–2009	14.7	369–869
2007–2016	17.2	383–403
2016	22.0	403–409
2017	–	409–411
2018	–	411–412

indicated the global CO_2 absorption by plants of 122.6 Gt C/yr and emission of 119.6 Gt C/yr. From the above-mentioned information it is evident that the net absorption of terrestrial ecosystems ranges from 1.4 to 3.0 Gt C/yr. Consequently, the terrestrial ecosystem is responsible for the net CO_2 absorption (terrestrial sink of CO_2) changing over 1960–2016 from 1.4 to 3.0 Gt C/yr (Table 2) (Le Quéré 2015, 2018; Ciais 2013).

The second important flux of CO_2 is the exchange of CO_2 between the atmosphere and oceans. The ocean waters absorb globally 92.2 Gt C/yr and simultaneously emit 90.6 Gt C/yr (Verlinden 2013). As a consequence, the ocean waters are responsible for the absorption of CO_2 ranging from 1.0 to 2.6 Gt C/yr (Table 2).

An increase in the CO_2 concentration in the atmosphere leads to an increase both in the absorption of CO_2 in the photosynthesis process and dissolution of CO_2 in ocean water. In the latter, the increase in the CO_2 content in water leads to its acidification, which will result in a decrease in the CO_2 dissolution (Schmiel et al. 2001; Beerling et al. 2001).

Excessively one-sided approach of mitigating CO_2 emission from anthropogenic sources, focusing on limiting fossil fuel combustion, may slow down the economic development of many countries (Bucher 2016; Cel et al. 2016; Xu et al. 2018; Lata-Garcia et al. 2018; Chen et al. 2018). Production of energy from renewable sources – especially promoted in the EU – which aims at the mitigation of CO_2 emissions, often leads to the creation of socio-economic problems and its effect on CO_2 reduction in many cases is not so great. Negative examples include the production of biodiesel fuel from the oil obtained from coconut palms, grown in Indonesia on the land acquired by burning off tropical forests or the production of ethanol from corn (Faragone et al. 2008; Searchinger et al. 2008). Promotion of biofuels was based on a simplified analysis and the assumption that the amount of CO_2 emitted during biofuels combustion is equal to the amount absorbed from the atmosphere in photosynthesis. Although this statement is true, it does not account for additional energy costs connected with the cultivation, harvest, and processing the plants into biofuel. Moreover, such assumption omits the fact that in order to create a plantation, another ecosystem was destroyed – such as a tropical forest or peatland – which would absorb greater amounts of CO_2 from the atmosphere (Cao and Cel 2015).

Therefore, introducing renewable energy sources requires an in-depth analysis of both socio-economic and environmental effects. Brazil is a country which successfully introduced ethanol for fueling cars on a large scale. A comprehensive programme of utilizing sugar cane for ethanol production was developed, which also took into consideration the socio-economic and environmental conditions (Dowbor 2013).

China, as the largest developing country with enormous renewable energy sources (e.g. solar, wind and biomass energy) has been intensively developing its renewable energy industry by making favorable policies on financial subsidy, tax, and price and by increasing investment in last three decades. Despite of these development, China is facing and resolving several problems e.g. coordinating the policy-makers to improve their efficiencies, balancing the investment and support among regions, and improving relative techniques and equipment (Zhang et al. 2009).

While the use of plants as a source of energy is widely advocated as a remedy for CO_2 emissions, the role of terrestrial ecosystems, including agriculture ones, in mitigating the increase of CO_2 concentration in the atmosphere remains underappreciated. These ecosystems emit 119 Gt C/yr due to respiration and biomass decomposition processes, and absorb 123 Gt C/year due to photosynthesis processes (IPCC 2013). Therefore, in order to neutralize the emission from combustion and cement production, which in 2017 amounted to 10.1 ± 0.5 Gt C/yr, it would be enough to intensify the CO_2 absorption by plants by 8.2%.

Therefore, the question may arise whether it would be preferable to focus on increasing the CO_2 absorption by terrestrial ecosystems rather than implementing expensive changes in energy production methods and investing in geological CO_2 sequestration.

The analysis of CO_2 absorption by agricultural crops will be carried out on the example of most popular cereals: barley, oat, wheat, rye and triticale in Poland and barley, wheat, rye and oat in China. During the harvest, three parts of plant are separated: grain, straw and roots. Biomass of roots is deposited directly in soil; straw also ended up in the soil in the past. At present, it is increasingly used as an energy source. Grains are mainly food for people and animals (Pawłowski et al. 2017; Read et al. 2001).

1. Materials and methods

The statistical data, information found in the relevant literature, and the results of own research were used to assess the potential absorption of CO_2 in the biomass of selected cereals in Poland and China. The details on the assumptions used for the calculations and their sources are provided in the further part of the work. The results of own examinations were obtained during the harvesting of particular cereals from the plots with the dimensions of 0.50 × 0.50 m. The plants were cut at the height of 5 cm. In the collected samples, grains were separated from straw. Roots were taken from the soil and cleaned. After drying at the temperature of 60°C, total mass and carbon content were determined for each of the extracted fractions. The obtained results were calculated per 1 ha by multiplying them by 4×10^4.

2. Results and discussion

The results of the assessment of crops biomass yield obtained in Poland and China were presented in Tables 4 and 5. The cereal grain production in Poland was calculated based on the data on grain crops yield acquired in 2017 (Statistics Poland 2018a). Straw biomass yield was estimated on the data concerning the straw/grain ratio given by Ludwicka and Grzybek (2010), and the roots biomass was assessed on the basis of the data given by Bolinder et al. (1997) and Amanullah (2014). According to the data of Ma et al. (2018) obtained on the basis of screening the data from 42 locations, it was assumed that the average carbon content in grains was 42.4%, in straw 43.3% and in roots 38.2%.

The lowest yield of grains amounting to 2.9 t/ha yr in China and 2.8 t/ha yr in Poland were achieved for oat, whereas the highest values: 5.4 t/ha yr in China and 4.7 t/ha yr in Poland were noted for wheat. The amount of absorbed carbon in the grains of studied cereals changed from 1.2 t C/ha yr for oat (both in Poland and China) to 2.3 t C/ha yr for winter wheat (in China). The yield of straw were the lowest (1.8 t/h yr) for spring wheat (in Poland) and highest (4.6 t/ha yr) for rye and winter triticale, which contained 0.8 and 2.0 t C/ha yr,

Table 4. Biomass yield and carbon sequestration by selected cereals cultivated in Poland

Tabela 4. Produkcja biomasy i sekwestracja węgla przez wybrane zboża uprawiane w Polsce

	Grain		Straw		Roots		Total carbon (t C/ha yr)
	biomass (t/ha yr)	carbon (t C/ha yr)	biomass (t/ha yr)	barbon (t C/ha yr)	biomass (t/ha yr)	barbon (t C/ha yr)	
Winter wheat	4.7	2.0	2.5	1.4	1.4	0.5	3.9
Spring wheat	3.6	1.5	1.8	0.8	1.1	0.4	2.7
Rye	2.8	1.2	4.6	2.0	2.2	0.8	4.0
Winter barley	4.1	1.7	3.2	1.4	2.3	0.9	4.0
Spring barley	3.4	1.5	3.0	1.3	2.7	1.0	3.8
Winter triticale	3.7	1.6	4.6	2.0	3.0	1.1	4.7
Spring triticale	3.1	1.3	3.9	1.7	1.3	0.5	3.5
Oats	2.8	1.2	3.0	1.3	1.9	0.7	3.2

Table 5. Biomass yield and carbon sequestration by selected cereals cultivated in China

Tabela 5. Produkcja biomasy i sekwestracja węgla przez wybrane zboża uprawiane w Chinach

	Grain		Straw		Roots		Total carbon (t C/ha yr)
	biomass (t/ha yr)	carbon (t C/ha yr)	biomass (t/ha yr)	barbon (t C/ha yr)	biomass (t/ha yr)	barbon (t C/ha yr)	
Winter wheat	5.4	2.3	3.6	1.5	0.8	0.3	4.1
Spring wheat	4.2	1.8	1.9	0.8	0.4	0.2	2.8
Rye	3.2	1.3	4.6	1.9	0.9	0.4	3.6
Barley	4.1	1.7	3.0	1.3	1.4	0.6	3.6
Oats	2.9	1.2	3.0	1.3	1.2	0.5	3.0

respectively. On the other hand, the lowest yield of roots (0.4 t/ha yr) was obtained for spring wheat (in China), while the highest (1.4 t/ha yr) for winter and spring barley (up to 2.7 t/ha yr), which correspond to 0.2 and 1.0 t C/ha, respectively.

The determined values (Tables 4 and 5) and data on croplands surface area acquired in 2017 (Statistics Poland 2018b; China Statistical Yearbook 2017) were used for the estimation of the total amount of carbon dioxide absorbed by the considered cereals in Poland and China. The results characterizing the amount of carbon absorbed annually by the biomass of particular cereals (in grain, straw and roots) were presented in Tables 6 and 7.

Table 6. Total annual biomass production and carbon amount in cereals produced in Poland in 2017

Tabela 6. Roczna produkcja biomasy poszczególnych zbóż uzyskana w Polsce w 2017 roku oraz ilość zawartego w nich węgla

	Grain		Straw		Roots		Total carbon (t C/ha yr)
	biomass (mln t/yr)	carbon (mln t C/yr)	biomass (mln t/yr)	carbon (mln t C/yr)	biomass (mln t/yr)	carbon (mln t C/yr)	
Winter wheat	9.2	3.9	4.9	2.7	2.7	1.0	7.7
Spring wheat	1.6	0.7	0.8	0.4	0.5	0.2	1.2
Rye	2.4	1.0	4.0	1.7	1.9	0.7	3.5
Winter barley	0.8	0.3	0.6	0.3	0.4	0.2	0.8
Spring barley	2.6	1.1	2.3	1.0	2.1	0.8	2.9
Winter triticale	4.3	1.8	5.3	2.3	3.5	1.3	5.5
Spring triticale	0.6	0.3	0.8	0.3	0.3	0.1	0.7
Oats	1.4	0.6	1.5	0.6	0.9	0.4	1.6
Total	22.8	9.8	20.1	9.4	12.3	4.7	23.8

Table 7. Total annual biomass production and carbon amount in cereals produced in China in 2017

Tabela 7. Roczna produkcja biomasy poszczególnych zbóż uzyskana w Chinach w 2017 roku oraz ilość zawartego w nich węgla

	Grain		Straw		Roots		Total carbon (t C/ha yr)
	biomass (mln t/yr)	carbon (mln t C/yr)	biomass (mln t/yr)	carbon (mln t C/yr)	biomass (mln t/yr)	carbon (mln t C/yr)	
Winter wheat	122.3	51.4	80.7	33.9	17.1	7.2	92.5
Spring wheat	6.3	2.6	2.9	1.2	0.6	0.3	4.1
Rye	0.5	0.2	0.7	0.3	0.1	0.1	0.6
Winter barley	1.4	0.6	1.0	0.4	0.4	0.2	1.2
Spring oat	0.4	0.2	0.5	0.2	0.2	0.1	0.5
Total	130.9	55.0	85.8	36.0	18.4	7.9	98.9

It shows that in 2017 the main cereals in Poland absorbed 9.8 mln t of carbon in the form of grains, 9.4 mln t of carbon as straw, and 4.7 mln t of carbon in the form of roots. Total value of carbon absorbed in the cereal crops in Poland corresponds to ca. 11.5% of total greenhouse gases emission in Poland in 2015, which was ca. 85 mln t of carbon (calculated on the data given in Table 8). From that 4.7 mln t of carbon is directly deposited in soils.

Table 8. Annual greenhouse gases emissions (mln t of CO_2 eq./yr) in Poland, excluding emissions and removals from category: Land use, land use change and forestry (Poland's National Inventory Report 2017)

Tabela 8. Roczna emisja gazów cieplarnianych (mln t ekw. CO_2/rok) w Polsce, z wyłączeniem emisji i pochłaniania z kategorii: Użytkowanie gruntów, zmiany użytkowania gruntów i leśnictwo

The 1980's decade		The 1990's decade		The 2000's decade		The 2010's decade	
year	emission	year	emission	year	emission	year	emission
1988	470.0	1990	376.0	2000	317.1	2010	332.1
1989	451.0	1991	373.4	2001	313.5	2011	331.7
		1992	363.7	2002	305.7	2012	324.2
		1993	364.1	2003	318.4	2013	319.9
		1994	359.6	2004	322.5	2014	307.6
		1995	361.3	2005	321.7	2015	310.6
		1996	375.3	2006	334.6		
		1997	366.6	2007	334.4		
		1998	337.3	2008	327.5		
		1999	327.6	2009	314.1		

In China 55 mln t of carbon annually is absorbed in cereal grains, 36 mln t of carbon is contained in straw and 7.9 mln t of carbon in roots. The carbon absorbed in root biomass is directly deposited in soil.

This does not mean that this amount of absorbed carbon undergoes permanent sequestration. Grains mainly serve as fodder. Part of the carbon, which was consumed by people and animals, is released in form of CO_2 in the course of breathing, and the rest is transformed into their biomass. In the past, straw in Poland was used as litter in animal husbandry; then it migrated into the soil with manure, where it was transformed into humic substances, similarly as the roots. At present, large amounts of straw is used for energy purposes. Unfortunately, large amount of the straw is directly combusted on the fields.

It is difficult to determine how much carbon is deposited permanently in the soil. The data presented in the paper depicts the amount of carbon fixed in particular parts of the biomass of cereals (grains, straws and roots) at harvest time of cereals. But, the microbiological processes occurring in soil lead to the decomposition of organic substances contained in soil, resulting in the release of carbon dioxide into the atmosphere.

Soil is one of the largest carbon stocks. On the global scale it contains ca. 1500 Gt of carbon (IPCC 2007). But the capability of soil to retain the carbon depends of different factors. It is known that the rate of organic substances decomposition in soil, and the release of carbon dioxide rely on the availability of oxygen, which infiltrates into the soil mainly during tillage. Therefore, in order to increase the storage of carbon in soil the zero-tillage is recommended.

Conclusions

It was shown that terrestrial ecosystems are able to absorb significant amounts of carbon dioxide, i.e., cereals alone can absorb 23.8 mln t C/yr in Poland and 98.9 mln t C/yr in China.

One hectare of cereal cropland in Poland absorbs from 2.7 t C/ha in case of winter wheat to 4.7 t C/ha in case of winter triticale, and in China from 2.8 t C/ha in case of spring wheat to 4.1 t C/ha in case of winter wheat.

These data indicate that wider application of agro-engineering techniques for carbon dioxide sequestration would facilitate the reduction of carbon dioxide emissions.

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CHARACTERISTIC OF CARBON DIOXIDE ABSORPTION BY CEREALS IN POLAND AND CHINA

Keywords

climate change, carbon dioxide emissions, terrestrial ecosystems, carbon dioxide sequestration, photosynthesis

Abstract

The reports of Intergovernmental Panel for Climate Change indicate that the growing emission of greenhouse gases, produced from the combustion of fossil fuels, mainly carbon dioxide, leads to negative climate changes. Therefore, the methods of mitigating the greenhouse gases emission to the atmosphere, especially of carbon dioxide, are being sought. Numerous studies are focused on so-called geological sequestration, i.e. injecting carbon dioxide to appropriate geological strata or ocean waters. One of the methods, which are not fully utilized, is the application of appropriate techniques in agriculture. The plant production in agriculture is based on the absorption of carbon dioxide in the photosynthesis process. Increasing the plant production directly leads to the absorption of carbon dioxide. Therefore, investigation of carbon dioxide absorption by particular crops is a key issue. In Poland, ca. 7.6 mln ha of cereals is cultivated, including: rye, wheat, triticale, oat and barley. These plants absorb approximately 23.8 mln t C annually, including 9.8 mln t C/yr in grains, 9.4 mln t C/yr in straw and 4.7 mln t C/yr in roots. The China, these cereals are cultivated on the area over 24 mln ha and absorb 98.9 mln t C/yr, including 55 mln tC/yr in grains, 36 in straw, and 7.9 mln t C/yr in roots. The second direction for mitigating the carbon dioxide emission into the atmosphere involves substituting fossil fuels with renewable energy sources to deliver primary energy. Cultivation of winter cereals as cover crops may lead to the enhancement of carbon dioxide removal from the atmosphere in the course of their growth. Moreover, the produced biomass can be used for energy generation.

CHARAKTERYSTYKA ABSORBCJI DWUTLENKU WĘGLA PRZEZ ZBOŻA W POLSCE I CHINACH

Słowa kluczowe

zmiana klimatu, emisje dwutlenku węgla, ekosystemy lądowe,
sekwestracja dwutlenku węgla, fotosynteza

Streszczenie

Z raportów Międzynarodowego Zespołu ds. Zmian Klimatu (IPCC) wynika, że rosnąca emisja gazów cieplarnianych, głównie dwutlenku węgla pochodzącego ze spalania paliw kopalnych, prowadzi do negatywnych zmian klimatu. Wobec takiego zagrożenia poszukuje się metod prowadzących do ograniczenia emisji do atmosfery gazów cieplarnianych, w szczególności dwutlenku węgla. Badania nad ograniczeniem emisji dwutlenku węgla koncentrują się głównie nad tzw. sekwestracją geologiczną, czyli zatłaczaniem dwutlenku węgla do odpowiednich pokładów geologicznych lub wód oceanicznych. Jednym ze sposobów, nie w pełni wykorzystanych, jest stosowanie odpowiednich technik w rolnictwie. Roślinna produkcja w rolnictwie oparta jest na absorpcji dwutlenku węgla w procesie fotosyntezy. Zwiększenie produkcji roślinnej prowadzi bezpośrednio do wzrostu absorpcji dwutlenku węgla. Dlatego ważnym zagadnieniem jest poznanie absorpcji dwutlenku węgla przez poszczególne uprawy. W Polsce na obszarze o powierzchni 7,6 mln ha uprawia się zboża: żyto, pszenicę, pszenżyto, owies i jęczmień. Rośliny te absorbują rocznie około 23,8 mln t C, z tego 9,8 mln t C/rok w ziarnach, 9,4 mln t C/rok w słomie i 4,7 mln t C/rok w korzeniach. W Chinach zboża te uprawiane są na powierzchni przekraczającej 24 mln ha i absorbują 98,9 mln t C/rok, z tego w ziarnach 55 mln t C/rok, w słomie 36 mln t C/rok, a 7,9 mln t C/rok w korzeniach. Drugim kierunkiem ograniczania emisji dwutlenku węgla do atmosfery jest zastępowanie paliw kopalnych, stanowiących źródło energii pierwotnej, przez odnawialne źródła energii. Uprawa zbóż ozimych jako roślin okrywowych może prowadzić do intensyfikacji usuwania dwutlenku węgla z atmosfery. Ponadto wyprodukowana biomasa może być wykorzystana jako surowiec do produkcji energii.