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# ROLE OF INTERCROPS IN THE ABSORPTION OF $CO_2$ EMITTED FROM THE COMBUSTION OF FOSSIL FUELS

Intercrops can play important role in the absorption of $CO_2$ emitted during the combustion of fossil fuels. They allow us to grow additional biomass on agricultural land what leads to the absorption of carbon dioxide in the photosynthesis process. Biomass produced could be used for the production of syngas and biogas. Thus intercrops grown in Poland sequestrate from 1.14 to 1.84 t C/ha globally they sequestrate about 1.9 million t C/year and provide the raw material for the production of 739 million m$^3$ of syngas/year.

## 1. INTRODUCTION

The growing concentration of $CO_2$ in the atmosphere from 277 ppm in 1751 (i.e., at the beginning of the Industrial Revolution) to 418 ppm in 2020 [14] is responsible for warming earth ecosystems, mostly due to energy generation from fossil fuels. It has reached globally 31.5 Gt $CO_2$ in 2020. Emissions of $CO_2$ from other industrial activities reached 2.57 Gt $CO_2$ and from land-use change 5.86 Gt $CO_2$ in 2020. According to various studies, many poorer developing countries of tropical and subtropical regions are especially vulnerable to global warming. The number of undernourished people in Sub-Saharan Africa may rise from 138 million in 1990 to 359 million in 2050 as a result of climate change. Some negative impacts are visible in many parts of the world.

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To take action on mitigation of climate change it would be helpful to analyze global natural $CO_2$ fluxes. There are four important global natural $CO_2$ fluxes in the Earth ecosystems [10]:

- $CO_2$ absorption by plants through photosynthesis,
- $CO_2$ emissions as a result of organisms and plants respiration and decomposition of biomass,
- $CO_2$ absorption by oceans,
- $CO_2$ emissions by degassing of ocean water.

Photosynthesis is responsible for the absorption of about 451 Gt $CO_2$/year and converting it into biomass. Simultaneously 435 Gt $CO_2$/year is emitted from the terrestrial ecosystem as a result of organisms and plants respiration and decomposition of biomass [7–9]. Oceans are the second Earth important ecosystem which absorbs about 293 Gt $CO_2$/year and simultaneously emits through degassing about 278 Gt $CO_2$/year [2, 6–9].

As a major remedial measure, ecological organizations are recommending limiting the use of fossil fuels as a source of energy. However, the one-side approach on the only reduction of $CO_2$ emissions through decreasing use of fossil fuels often leads to the creation of socio-economic problems [4, 11, 17, 18]. Negative examples are 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 [1, 5, 15]. The promotion of these biofuels was based on the assumption that the amount of $CO_2$ emitted during biofuels combustion is equal to the amount absorbed by plants from the atmosphere in the photosynthesis process. Although this statement is true, it does not take into account additional energy used during cultivation, harvesting, and processing plants into biofuels. Moreover, such an assumption omits the fact that in order to create a plantation, another ecosystem was destroyed – such as tropical forest or peatland – which would absorb greater amounts of $CO_2$ from the atmosphere.

While the use of biomass from plants as a source of energy is widely recommended for mitigation of $CO_2$ emissions, the potential role of whole agriculture in mitigation of $CO_2$ concentration in the atmosphere is not widely recognized [12, 13]. An increase of $CO_2$ absorption by plants in the photosynthesis process only by 8.9% would allow the completion of the whole annual anthropogenic $CO_2$ emissions. One possibility to increase $CO_2$ absorption by agriculture activity is increased growth of intercrops. Cultivation of intercrops allows additional absorption of $CO_2$ and converting it into below-ground (roots) and above-ground (shoots and leaves) biomass. The below-ground biomass is permanently sequestrated in the soil and transformed into humic substances. The above-ground biomass may be used as green fertilizer and sequesters in the soil similar to below-ground biomass or may be used as raw material for the production of syngas through its thermal gasification or the production of biogas through methane fermentation.

In Poland and other European countries, it is possible to cultivate intercrops such as white mustard, tansy phacelia, red clover, winter rye, winter vetch, narrow-leafed lupine, and mixtures of yellow lupine with serradella, spring vetch with fields pea, oat with spring vetch and field pea. Widespread cultivation of intercrops can make a significant contribution to reducing $CO_2$ emissions by immobilization in biomass and additionally, could provide substrate for efficient biofuel production.

Taking into account the high worldwide demand for energy, unstable and uncertain petroleum sources, and concern over global climate change more attention should be paid to the possibility of using agriculture for absorption of $CO_2$ from the atmosphere and providing raw materials for renewable energy production. The introduction of biomass from intercrops to the soil will increase the fertility of the soil and will consequently lead to increased production of food from main crops and as well additional $CO_2$ sequestration in increased food production.

## 2. MATERIALS AND METHODS

Intercrops were cultivated on plots 0,5×0,5 m. The plants were cut at the height of 5 cm above-ground, roots were taken from the soil and cleaned. The mass of below-ground and above-ground biomass was determined after drying at the temperature of 60 °C. The carbon content was determined using a high-performance TOC analyzer (TOC Sensor 6000i). Syngas production from the above-ground biomass was determined by heating the dried biomass at 550 °C. Gas pyrolysis products were analyzed using standard gas chromatography techniques.

## 3. RESULTS AND DISCUSSION

Yields of above-ground, below-ground and total biomass of intercrops are presented in Table 1. The yield of below-ground biomass is the lowest (0.07 t biomass/ha) for red clover, highest (0.3 t biomass/ha) for mixture of yellow lupine and serradelle. The highest yield of above-ground biomass (4.26 t biomass/ ha) is for white mustard while the lowest (2.64 t biomass/ha) is for narrow-leafed lupine.

Table 1

Yield of biomass of intercrops grown in Poland [t/ha]

| Intercrops | Below-ground biomass | Above ground biomass | Total |
|---|---|---|---|
| White mustard | 0.13 | 4.26 | 4.39 |
| Tansy phacelia | 0.08 | 3.98 | 4.06 |
| Yellow lupine + serradella mixture | 0.30 | 3.40 | 3.70 |
| Oats + spring vetch + field pea mixture | 0.16 | 3.22 | 3.38 |
| Red clover | 0.07 | 2 | 2.07 |
| Winter rye | 0.13 | 4.07 | 4.2 |
| Spring vetch + field pea mixture | 0.21 | 3.07 | 3.28 |
| Winter vetch | 0.12 | 2.97 | 3.09 |
| Narrow-leaded lupiene | 0.29 | 2.64 | 2.93 |

Table 2

Carbon sequestration by intercrops grown in Poland [t C/ha]

| Intercrops | Below-ground biomass | Above-ground biomass | Total |
|---|---|---|---|
| White mustard | 0.05 | 1.79 | 1.84 |
| Tansy phacelia | 0.03 | 1.67 | 1.70 |
| Yellow lupine + serradella mixture | 0.21 | 1.43 | 1.64 |
| Oats + spring vetch + field pea mixture | 0.07 | 1.35 | 1.42 |
| Red clover | 0.03 | 1.11 | 1.14 |
| Winter rye | 0.05 | 1.71 | 1.76 |
| Spring vetch + field pea mixture | 0.18 | 1.45 | 1.63 |
| Winter vetch | 0.05 | 1.25 | 1.30 |
| Narrow-leaded lupiene | 0.12 | 1.11 | 1.23 |

Table 3

Yield of syngas produced from biomass of intercrops grown in Poland

| Intercrops | Yield of syngas | |
|---|---|---|
| | [$m^3$/t biomass] | [$m^3$/ha] |
| White mustard | 183 | 780 |
| Tansy phacelia | 171 | 680 |
| Yellow lupine + serradella mixture | 185 | 629 |
| Oats + spring vetch + field pea mixture | 172 | 554 |
| Red clover | 172 | 463 |
| Winter rye | 185 | 753 |
| Spring vetch + field pea mixture | 156 | 540 |
| Winter vetch | 172 | 511 |
| Narrow-leaded lupiene | 193 | 509 |

Table 4

Potential syngas production from intercrops grown in Poland

| Intercrops | Area [ha] | Total amount of syngas [million $m^3$/year] |
|---|---|---|
| White mustard | 225 000 | 175.5 |
| Tansy phacelia | 188 000 | 127.8 |
| Yellow lupine + serradella mixture | 163 000 | 102.5 |
| Oats + spring vetch + field pea mixture | 150 000 | 83.1 |
| Red clover | 113 000 | 49 |
| Winter rye | 106 000 | 79.8 |
| Spring vetch + field pea mixture | 100 000 | 54 |
| Winter vetch | 69 000 | 35.3 |
| Narrow-leaded lupiene | 63 000 | 32.1 |
| Total | 1 177 000 | 739.1 |

Table 5

Total carbon sequestration by intercrops grown in Poland

| Intercrops | Area [ha] | Total amount of carbon sequestrated [t C/year] |
|---|---|---|
| White mustard | 225 000 | 414 000 |
| Tansy phacelia | 188 000 | 320 000 |
| Yellow lupine + serradella mixture | 163 000 | 267 000 |
| Oats + spring vetch + field pea mixture | 150 000 | 231 000 |
| Red clover | 113 000 | 129 000 |
| Winter rye | 106 000 | 187 000 |
| Spring vetch + field pea mixture | 100 000 | 163 000 |
| Winter vetch | 69 000 | 90 000 |
| Narrow-leaded lupiene | 63 000 | 77 000 |
| Total | 1 177 000 | 1 860 000 |

Data on carbon sequestration by the intercrops grown in Poland are presented in Table 2. The lowest below-ground sequestration (0.03 t C/ha) is for tansy phacelia and the highest (0.21 t C/ha) is for the mixture of yellow lupine with serradella. The lowest of the above group sequestration (1.11 t C/ha) is for narrow-leafed lupine and the highest (1.79 t C/ha) is for white mustard.

The below-ground biomass is deposited in the soil while above-ground biomass may be used as raw materials for the production of syngas or biogas. The use of above-ground biomass for syngas or biogas production is very beneficial from an environmental standpoint because it provides the fuel of low impact on the environment. Yields of syngas produced from intercrops cultivated in Poland are presented in Table 3 and the total potential of syngas production is presented in Table 4.

The highest yield of 193 $m^3$/t biomass was obtained for narrow-leased lupin while the lowest yield of 156 $m^3$/t biomass was obtained for the mixture of spring vetch and field pea. In the case of syngas yield per 1 ha, the highest yield 780 $m^3$ of syngas/ha was obtained for white mustard while the lowest one 463 $m^3$ of syngas/ha for red clover. It is possible to grow intercrops in Poland on the area of 1177 million ha and reach syngas production of 739 million $m^3$/year. This would allow one to sequester 1.86 million t C/year (Table 5).

REFERENCES

[1] Chen S., Liu K., Ding D., Yue Z., Bo Z., Tang Y., The effect of Green R&D Activities on China's $SO_2$ emissions. Evidence from a Panel Threshold Model. *Problems of Sustainable Development*, 2021, 16 (2), 147–151. DOI: 10.35784/pe.2021.2.15.

[2] Ciais P., Gasser T., Paris J.D., Caldeira K., Raupach M.R., Canadell J.G., Patwardhan A., Friedlingsein P., Piao S.L., Gitz V., *Attributing the increase in atmospheric $CO_2$ to emitters and absorbers*, Nat. Clim. Change, 2013, 3, 926–931. DOI: 10.1038/nclimate1942.

[3] CIAIS P., SABINE C., *Climate Change 2013. The Physical Science Basis, Chapter 6. Carbon and other biogeochemical cycles*, Working Group I, Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cabridge University Press, 2013, 465–570.
[4] CZEKAŁA W., TARKOWSKI F., POCHWATKA P., *Social Aspects of Energy Production from Renewable Sorces*, Probl. Sust. Dev., 2021, 16 (1), 61–66. DOI: 10.35784/pe.2021.1.04.
[5] FARGIONE J., HILL J., TILMAN D., POLASKY S., HAWTHORNE P., *Land clearing and the biofuel carbon debt*, Science, 2008, 319, 1235–1238. DOI: 10.1126/science.1152747.
[6] FRIEDLINGSTEIN P. et al., *Global Carbon Budget 2020*, Earth Syst. Sci. Data, 2020, 12, 3269–3340. DOI: 10.5194/essd-12-3269-2020.
[7] IPCC 2013. *Fifth IPCC Report Climate Change 2013*.
[8] IPCC, 2014 *Fifth Assessment Report AR5, Climate Change*.
[9] IPCC, 2021 *Sixth Assessment Report AR6, Climate Change*.
[10] LE QUÉRÉ C. et al., *Global carbon budget*, Earth Syst. Sci. Data, 2018, 10, 2141–2194. DOI: 10.5194/essd-10-2141-2018.
[11] PAWŁOWSKI A., *The sustainable revolution*, Probl. Sust. Dev., 2009, 4 (1), 65–76.
[12] UDO V., PAWŁOWSKI A., *Human progress towards equitable sustainable development. A philosophical exploration*, Probl. Ekorozw./Probl. Sust. Dev., 2009, 4 (2), 23–44.
[13] PAWŁOWSKI L., PAWŁOWSKA M., CEL W., WANG L., LI C., MEI T., *Characteristic of carbon dioxide absorption by cereals in Poland and China*, Min. Res. Manage., 2019, 35 (1),165–176. DOI: 10.24425 /gsm.2019.128205.
[14] PAWŁOWSKI L., ZHOU G., LITWIŃCZUK Z., *The Role of Agriculture in Climate Change Mitigation*, CRC Press, London 2020. DOI: 10.1201/9781003002734.
[15] RITCHIE H., ROSER M., *$CO_2$ and Greenhouse Gas Emissions*, Our World in Data, 2020.
[16] SEARCHINGERT., HEIMLICH R., HOUGHTON R.A., DONG F., ELOBEID A., FABIOSA J., TOKGOZ S., HAYES D., YU T.H., *Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land--use change*, Science, 2008, 319, 1238–1240. DOI: 10.1126/science.1151861.
[17] SZTUMSKI W., *Reflection on the human living environment in connection with sustainable development*, Probl. Ekorozw./Probl. Sust. Dev., 2021, 16 (1), 39–44. DOI: 10.35784/pe.2021.1.04.
[18] ŻUKOWSKA G., MYSZURA M., ZDEB M., PAWŁOWSKA M., *Carbon sequestration in soil as a sustainable way of greenhouse effect mitigation*, Probl. Ekorozw./Probl. Sust. Dev., 2020, 15 (2), 195–205. DOI: 10.35784/pe.2020.2.19.