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Greenhouse gas emissions from rape seed cultivation for FAME production in Poland

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Abstract

The production of bio diesel from rape seed, in accordance with Directive 2009/28/EC (RED), requires estimation on greenhouse gas (GHG) emissions in the life cycle of bio fuels and reduction size in comparison to diesel as fossil fuel. The study sought a reduction in GHG emissions from agriculture, in the full life cycle of Fatty Acid Methyl Esters (FAME) by optimisation of nitrogen fertilisation of rape seed, the selection of fertilisers with lower emissions arising from their production and increased organic carbon sequestration in the soil by the use of reduced or no tillage (direct sowing). It was found that an optimisation of the nitrogen (N) dose and manipulations of fertiliser N type does not guarantee a 50% reduction in GHG emissions. The reduction of GHG emissions under reduced tillage, which increases the organic carbon sequestration in the soil, is achievable only at a dose of 150 kg N ha^{-1} in the form of a urea ammonium nitrate (UAN) solution or mixture of ammonium nitrate + ammonium sulphate. The increase of organic carbon sequestration in the soil through the conversion of conventional oilseed rape cultivation to a no tillage system increases the reduction of GHG emissions by 58-63% at a dose of 150 kg N ha^{-1} and 54-59% at a dose of 180 kg N ha^{-1}.

Key words: Rapeseed, FAME, GHG emissions, emission reductions, organic carbon sequestrations, RED.

Introduction

The production of raw materials for fuel purposes is so far the only type of agricultural production in which the EU regulates in detail the requirements for size and greenhouse gas emission (GHG) reduction emissions, and indirectly increases the organic carbon sequestration in the soil as a result of improved agricultural technology [3, 4]. Average GHG emissions generated in the production of rapeseed for fuel purposes in the NUTS-2 in Poland equals to 24.28 g CO_2 eq. MJ^{-1} and is less than 29 g CO_2 eq. MJ^{-1}, which is the default value according to Renewable Energy Directive (RED) Annex V. D [3]. At such emission levels, agri-refineries in Poland have been able to achieve the reduction required by the RED GHG emissions by 35% compared to a fossil fuel reference for 01.04.2013.

However, in order to achieve the goal set by RED in reducing emissions by 50% from 2017 requires seeking opportunities to further reduce GHG emissions in the life cycle of FAME. Some opportunities in this respect also exist for agricultural GHG emissions. The largest shares in its structure are emissions from the use and production of nitrogen fertilisers, which is mainly due to emissions of nitrous oxide (N_2O) [7]. It is essential to find out how big the savings in agricultural emissions can be achieved in rapeseed cultivation through optimum rates of N fertiliser and application of fertilisers with the lowest emissions during the production process. Rapeseed was characterised with high greenhouse gas emissions associated with high demands of fertilisers [2]. Based on the RED regulations, it is possible to influence the emissions in the full life cycle of FAME by increasing the sequestration of organic carbon in the soil as a result of improved agricultural technology. Reducing the intensity of soil cultivation lowers energy consumption and the emission of carbon dioxide (CO_2), while carbon sequestration is raised through the increase of soil organic matter (SOM) [6]. There has been growing concern about soil productivity and in the impact of management practices on the environment [9-11]. The methodology for estimating carbon stocks has been determined within RED [4]. The aim of this study was to estimate: (i) the value and structure of agricultural GHG emissions from rapeseed production, (ii) the optimal dose of N fertiliser, resulting in the lowest GHG emissions by using selections of fertilisers with the lowest emissions arising in their production, and (iii) the value of savings for GHG emissions in the life cycle of rapeseed through the use of improved cultivation such as reduced tillage and no tillage systems.

Materials and Methods

The study uses the results of surveys carried out in all plants producing nitrogenous fertilisers in Poland and in 1,218 farms producing rapeseeds (3% of the total number of farms engaged in such production). The survey within all producers of nitrogen fertilisers in Poland has identified GHG emissions from the production of these fertilisers. They are presented as weighted average emissions (g CO_2 eq kg^{-1} N) for different ranges of nitrogen fertiliser (the weight was the size of the output of each range in each plant producing fertilisers). The farm surveys were collecting data on obtained seed yield (kg ha^{-1}), the relative humidity (%), dose of nitrate (N), lime (CaO), phosphorus pentoxide (P_2O_5), potassium oxide (K_2O), and pesticides (kg ha^{-1}) and the amount of oil consumed (MJ ha^{-1}), as well as fuel oil for drying seeds (MJ^{-1} seed of rapeseed). The straw yields have been estimated based on the yield of seeds. The average size of the obtained data was compared with data from a European database of JRC [8].

The Biograce calculator 4b [1] estimates agricultural emissions and GHG emissions in the life cycle of FAME. The calculator takes into account the methodological requirements set out in the RED [4] and subsequent decisions of the European Commission [3] as well as the Fuel Quality Directive (FQD) (2009/30/EC) [5]. The emissions and structure of agricultural GHG emissions were estimated based on average values characterising the production technology for 1,218 farms. Estimates of emissions and emission reductions during the life cycle of FAME used default values of Biograce for processing and transport of FAME.

The estimates of carbon stocks were done with the recommended method [3], however, instead of using default soil organic SOC_{ST} for High Activity Clay Soils (HACS), which are 50 and 95 t C ha^{-1} for cold temperate climate dry and moist, respectively, the results of our own database were inserted. They indicate that SOC_{ST} in Poland is on average 41 t C ha^{-1} and is independent from the climatic zone. The estimated value of Annual Carbon Stock Change for HACS soils cultivated in reduced tillage and no tillage, averaged 0.126 and 0.614 t CO_2 ha^{-1} yr^{-1}, respectively. These values were estimated and compared to a full tillage cultivation system, leaving the total amount of crop residue on the field. It is obligatory in Poland, under a cross-compliance agreement, which prescribes ploughing straw on farms with no inventory, which constitutes 40% of all farms in Poland. The optimal rates of nitrogen for yields of rapeseed were obtained by a boundary line approach. A scatter plot is drawn between yields and nitrogen rates for 1,218 observations. Data points (boundary points), which were located on the outer rim of the data body, were chosen. Polynomial and two segment linear regressions were fitted. The lower optimal N rate is obtained as the break point of the segment linear regression. The upper optimal N rate is obtained as a maximum of polynomial regression. The nitrogen reaction curve fitted as boundary line is used to calculate the linear multiple regression between agriculture GHG emissions vs. yield and N rates. The estimation of this relation was possible because yields and N rates are low correlated (r < 0.5). The ranges of data were: GHG emissions without allocations 11.89-44.52 g CO_2 eq MJ^{-1}, grain yield 4000-9500 kg ha^{-1} (moisture content 15%) and N rates 61-236 kg ha^{-1}.

Results and Discussion

The identified GHG emissions generated during the production of nitrogen fertilisers in Poland were lower than the emissions recommended for use by the JEC database (Table 1). The data was used in subsequent estimates, which resulted in a significant reduction in agricultural emissions in relation to the estimates made for the average emissions for the EU that were taken at a level of 5880.6 g CO_2 eq kg^{-1} N.

Production technology of oilseed rape in Poland did not differ substantially from the technology characterised for the EU (Table 2). The average values characterising the production technology of oilseed rape in Poland were used in subsequent estimates.

The structure of agricultural GHG emissions, assuming a weighted average of emissions from the production of fertilisers (3,414.2 GCO2 eq kg^{-1} N, Table 1), indicates that the greatest impact on agricultural greenhouse emissions were associated with the use and production of nitrogen fertilisers (Fig. 1). However, in the near future, a further reduction of GHG emissions in the production of nitrogen fertilisers appears to be difficult to achieve in Poland. Theoretically, it is possible to reduce agricultural emissions by optimising the dose and selection of the ranges of N fertiliser with lower emissions arising from their production.

Table 1. The average weighted GHG emissions for different nitrogen fertilisers produced in Poland.

Fertiliser	Emission gCO_2 eq kg^{-1} N
Urea	3,683.9
Ammonium nitrate	3,494.5
Urea ammonium nitrate solution (UAN)	3,080.0
Ammonium sulphate	1,969.2
Calcium ammonium nitrate (CAN)	4,007.6
Saletrosan® 26 makro	5,333.0
Calcium ammonium nitrate with magnesium (CANMg) (Salmag)	5,012.0
Multicomponent NPK*	2,577.0
Multicomponent NP*	2,887.0
Average weighted GHG emissions for N fertiliser	3,414.2
EU [4]	5,880.6

Table 2. Parameters for rape seed production technology for Poland and EU.

Parameter	Unit	Poland	EU [4]
Yield	kg ha^{-1} yr^{-1}	3,279	3,113
Moisture content	%	9	10
Diesel use	MJ ha^{-1} yr^{-1}	2,668	2,963
N-fertiliser	kg ha^{-1} yr^{-1}	168	137
Manure	kg N ha^{-1} yr^{-1}	0	-
P_2O_5-fertiliser	kg ha^{-1} yr^{-1}	56	34
K_2O-fertiliser	kg ha^{-1} yr^{-1}	91	50
CaO-fertiliser	kg ha^{-1} yr^{-1}	177	-
Pesticides	kg s.a. ha^{-1} yr^{-1}	1.8	1.2
Seeds	kg ha^{-1} yr^{-1}	3.4	6.0
N_2O field emission	kg N_20 ha^{-1} yr^{-1}	3.08	3.11

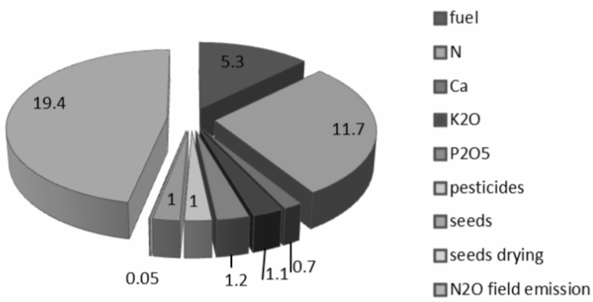

Figure 1. The structure of agricultural emissions from the production of rape seed in Poland (g eq CO_2 MJ^{-1}).

The regression between emissions of GHG yield of grain had given equation:

$$\text{Emissions} = 24.3915 - 0.00562325 * \text{Yield} + 0.108147 * \text{N rates};\ R^2 = 93.0\%$$

The regression was statistically significant for both independent variables, which had different effects (Figs 2 and 3).

The doses in the studied farms were optimal levels and amounted to 150-180 kg N ha^{-1}. With an average yield of 3.28 t ha^{-1} and the given doses of N agro-refinery did not obtain a 50% reduction of GHG emissions, and this is regardless of what kind of fertiliser which was applied in the production of rape seed (Tables 3 and 4). In this situation, a further reduction of GHG emissions should be

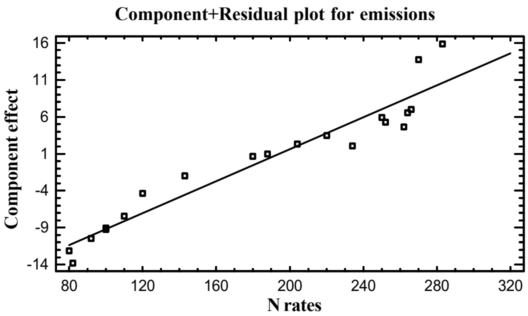

Figure 2. Component effects of N rates on agricultural emissions of GHG (first stepwise regression variable; R^2=70.8%).

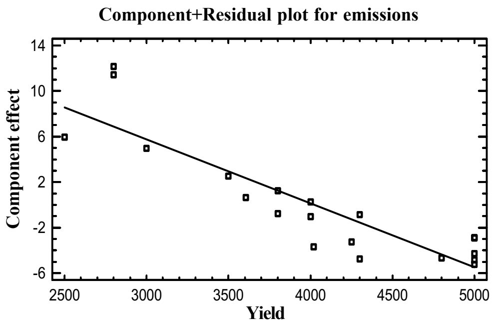

Figure 3. Component effects of yields on agricultural emissions of GHG (second stepwise regression variable; R^2=93.0%).

Table 3. Estimations of greenhouse gas emissions for rape seed, depending on the applied fertiliser dose (150 kg N ha^{-1}).

Fertiliser	Emission CO_2 eq kg^{-1} N	Agricultural emission CO_2 eq MJ^{-1} without allocation	Agricultural emission CO_2 eq MJ^{-1} with allocation	Emission reduction %
Ammonium nitrate 150 kg	3,494.5	38.54	22.58	46
Urea ammonium nitrate solution (UAN) RSM 150 kg	3,080.0	37.18	21.78	47
Calcium ammonium nitrate 150 kg	4,007.6	40.23	23.57	44
Urea 30 kg, ammonium nitrate 120 kg	3,532.4	38.67	22.65	46
Ammonium sulphate 30kg, ammonium nitrate 120 kg	3,189.4	37.54	21.99	46
Saletrosan® 26 makro 30kg, ammonium nitrate 120 kg	3,862.2	39.75	23.29	45
Multicomponent NPK 30 kg, ammonium nitrate 120 kg	3,311.0	37.94	22.23	46

Table 4. Estimates of greenhouse gas emissions for rape seed, depending on the applied fertiliser dose (180 kg N ha^{-1}).

Fertiliser	Emission CO_2 eq kg^{-1} N	Agricultural emission CO_2 eq MJ^{-1} without allocation	Agricultural emission CO_2 eq MJ^{-1} with allocation	Emission reduction %
Ammonium nitrate 180 kg	3,494.5	44.22	25.91	42
Urea ammonium nitrate solution (UAN) 180 kg	3,080.0	42.58	24.95	43
Calcium ammonium nitrate 180 kg	4,007.6	46.25	27.10	40
Urea 30 kg, ammonium nitrate 150 kg	3,648.9	44.83	26.27	41
Ammonium sulphate 30kg, ammonium nitrate 150 kg	3,305.9	43.48	25.47	42
Saletrosan® 26 makro 30kg, ammonium nitrate 150 kg	3,978.7	46.13	27.03	40
Multicomponent NPK 30 kg, ammonium nitrate 150 kg	3,427.5	43.96	25.75	42

sought through an increase of organic carbon sequestration in the soil. In the case of agricultural holdings without feedstock, it is very desirable, because they do not apply manure fertilisation, which could be the greatest help to increase the sequestration. The study assumes that the farms will leave the entire amount of crop residue on the field and use reduced tillage or no tillage.

Improved agricultural cultivation is limited only to reduced tillage and leaving all residues on the field, although this residue will not always ensure the achievement of a 50% reduction (Tables 5 and 6). The farms could be recommended to increase carbon sequestration through the use of green manure and cover crops. However, this recommendation would have limited chance of success, because it complicates the technology of production, and at the same time in Poland, it often leads to a reduction in the yield of cash-crops. Consequently, rapeseed production should be considered in the no tillage system (Table 7 and 8), remembering that this production system neither in Poland nor in Europe, has not a sufficiently well-established tradition in the production of these crops and will be considered as risky. In addition, relatively the no tillage system is expensive because of the need to buy new equipment. In Poland, even in soils with a good culture, the emergence of oilseed rape in such a system can be quite unreliable, which may increase the volatility of the yield in years to come. So this is an option that exists in RED, but it seems to hold little chance for a wide application in Polish farms.

Conclusions

An attempt to optimise the dose and selection of low emission N fertilisers does not ensure a reduction in the life cycle of FAME by up to 50%. The reduced tillage increases the organic carbon sequestration in the soil; however, this limit is only achievable at a dose of 150 kg N ha^{-1} applied as UAN, or in a mixture of ammonium

Table 5. Estimates of greenhouse gas emissions from rape, depending on the applied fertiliser dose (150 kg N ha^{-1}, reduced tillage ensured by organic carbon sequestration 0.1260 t CO_2 ha^{-1} yr^{-1}).

Fertiliser	Emission CO_2 eq kg^{-1} N	Agricultural emission CO_2 eq MJ^{-1} without allocation	Agricultural emission CO_2 eq MJ^{-1} with allocation	Emission reduction %
Ammonium nitrate 150 kg	3,494.5	38.54	22.58	49
Urea ammonium nitrate solution (UAN) 150 kg	3,080.0	37.18	21.78	50
Calcium ammonium nitrate 150 kg	4,007.6	40.23	23.57	48
Urea 30 kg, ammonium nitrate 120 kg	3,532.4	38.67	22.65	49
Ammonium sulphate 30kg, ammonium nitrate 120 kg	3,189.4	37.54	21.99	50
Saletrosan® 26 makro 30kg, ammonium nitrate 120 kg	3,862.2	39.75	23.29	48
Multicomponent NPK 30 kg, ammonium nitrate 120 kg	3,311.0	37.94	22.23	49

Table 6. Estimates of greenhouse gas emissions from rape, depending on the applied fertiliser dose (180 kg N ha^{-1}, reduced tillage ensured by organic carbon sequestration 0.1260 t CO_2 ha^{-1} yr^{-1}).

Fertiliser	Emission CO_2 eq kg^{-1} N	Agricultural emission CO_2 eq MJ^{-1} without allocation	Agricultural emission CO_2 eq MJ^{-1} with allocation	Emission reduction %
Ammonium nitrate 180 kg	3,494.5	44.22	25.91	45
Urea ammonium nitrate solution (UAN) 180 kg	3,080.0	42.58	24.95	46
Calcium ammonium nitrate 180 kg	4,007.6	46.25	27.10	44
Urea 30 kg. ammonium nitrate 150 kg	3,648.9	44.83	26.27	45
Ammonium sulphate 30kg ammonium nitrate 150 kg	3,305.9	43.48	25.47	45
Saletrosan® 26 makro 30kg. ammonium nitrate 150 kg	3,978.7	46.13	27.03	44
Multicomponent NPK 30 kg. ammonium nitrate 150 kg	3427.5	43.96	25.75	45

Table 7. Estimates of greenhouse gas emissions from rape depending on the applied fertiliser dose (150 kg N ha^{-1}. no tillage ensured by organic carbon sequestration 0.6142 t CO_2 ha^{-1} yr^{-1}).

Fertiliser	emission CO_2 eq kg^{-1} N	Agricultural emission CO_2 eq MJ^{-1} without allocation	Agricultural emission CO_2 eq MJ^{-1} with allocation	Emission reduction %
Ammonium nitrate 150 kg	3,494.5	38.54	22.58	62
Urea ammonium nitrate solution (UAN) 150 kg	3,080.0	37.18	21.78	63
Calcium ammonium nitrate 150 kg	4,007.6	40.23	23.57	61
Urea 30 kg ammonium nitrate 120 kg	3,532.4	38.67	22.65	62
Ammonium sulphate 30kg ammonium nitrate 120 kg	3,189.4	37.54	21.99	62
Saletrosan® 26 makro 30kg, ammonium nitrate 120 kg	3,862.2	39.75	23.29	61
Multicomponent NPK 30 kg. ammonium nitrate 120 kg	3,311.0	37.94	22.23	62

Table 8. Estimates of greenhouse gas emissions from rape depending on the applied fertiliser dose (180 kg N ha^{-1}. no tillage ensured by organic carbon sequestration 0.6142 t CO_2 ha^{-1} yr^{-1}).

Fertiliser	Emission CO_2 eq kg^{-1} N	Agricultural emission CO_2 eq MJ^{-1} without allocation	Agricultural emission CO_2 eq MJ^{-1} with allocation	Emission reduction %
Ammonium nitrate 180 kg	3,494.5	44.22	25.91	58
Urea ammonium nitrate solution (UAN) 180 kg	3,080.0	42.58	24.95	59
Calcium ammonium nitrate 180 kg	4,007.6	46.25	27.10	56
Urea 30 kg. ammonium nitrate 150 kg	3,648.9	44.83	26.27	57
Ammonium sulphate 30kg, ammonium nitrate 150 kg	3,305.9	43.48	25.47	58
Saletrosan® 26 makro 30kg, ammonium nitrate 150 kg	3,978.7	46.13	27.03	56
Multicomponent NPK 30 kg. ammonium nitrate 150 kg	3,427.5	43.96	25.75	58

nitrate + ammonium sulphate. The increase of C sequestration in the soil through the transition from traditional rapeseed cultivation to no tillage increases the reduction of GHG emissions by 58-63% for a dose of 150 kg N ha^{-1} and 54-59% for a dose of 180 kg N ha^{-1}. However, this option because of the high risk of yields decline seems to promise little chance for wide dissemination in practice.

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