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Emission saving opportunities for corn cultivation for ethanol in Poland

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Abstract

Corn (maize) is one of the main raw materials for ethanol production in the European Union. Among agricultural feedstock dedicated for biofuels, it is put under regulation in terms of greenhouse gas emission in the life cycle of ethanol production. This study is focused on corn cultivation in Poland and the possibilities to mitigate the greenhouse gas emission at the stage of crop cultivation. The main opportunities come from N fertilization optimization (rates and assortment) as well from increase in soil organic carbon sequestration by improving crop management (reduced tillage and no-tillage). The results show that ethanol produced from conventional tillage corn cultivation, including typical GHG emissions from N fertilizer production, guarantee the at least 35% greenhouse gas savings to petrol as fossil fuel reference. Moreover, the future required life cycle GHG emission savings of 50-60% for corn based ethanol production shall be reached in Poland if applying reduced and no-tillage cultivation of corn.

Key words: Corn, ethanol, GHG emissions, emission savings, organic carbon sequestrations.

Introduction

In the European Union, sustainability criteria for transportation biofuels have been set within the Renewable Energy Directive (RED) [1]. Criteria for the most important sustainability, the greenhouse gas (GHG) emission savings from the use of biofuels or bioliquids compared to fossil fuels have been established. From the 1 April 2013 the GHG savings have to be at least 35%. From 2017 onwards these savings have to be at least 50% and from 2018 onwards 60% for biofuels produced in installations that start their production in 2017 or later. The emission criteria have been modified in the European Commission proposal dated 17 October 2012, which requires at least 60% for biofuels produced in installations starting operation after 1 July 2014 [2]. In the case of installations that were in operation on or before 1 July 2014, biofuels shall achieve a GHG savings of at least 35% until 31 December 2017 and at least 50% from 1 January 2018. Biofuels not fulfilling these newly formulated sustainability criteria may not be taken into account for: (i) calculating the shares of energy from renewable sources, (ii) measuring compliance with the targets set in the RED, (iii) the eligibility for financial support for biofuels.

Default values of GHG emissions for the entire production chain of various biofuels as well as for each part of the chain (cultivation, processing and transport) are included in the Annex V, part D of the Renewable Energy Directive. The GHG emissions referring to the agricultural feedstock production include the emissions from crop cultivation as well as soil organic carbon (SOC) changes. For corn dedicated for ethanol production, the default value given in Annex V is 20 g CO_2 eq. MJ^{-1} of ethanol[1]. In Poland, the average GHG emission for corn production estimated at NUTS-2 level amounted to 19.66 g CO_2 eq. MJ^{-1}, and is very close to the default value of the RED. With reference to this, the corn ethanol produced in Poland is capable to reach the currently required at least 35% greenhouse gas emission savings. However, from 1 January 2018, the required GHG emission savings shall be at least 50%, which force the ethanol industry to seek for any opportunities to reduce the life cycle GHG emissions for corn ethanol. According to the RED, this can be done by substituting the technological fuel in the ethanol processing plant with renewable energy. However, some emission reduction opportunities are possible at the feedstock production level.

The largest GHG emissions for crop production, namely N_2O emissions, are attributed to the production and field application of N fertilizers [3]. With regard to that, the research question is how much greenhouse gas emission reduction can be achieved for corn due to the application of optimal N fertilizer does as well as the selection of N fertilizer charged with the lowest N_2O emissions with regard to its industrial production. Moreover, the overall GHG calculations in corn ethanol production can be influenced by the soil carbon accumulation via improved agricultural management, which was taken into account by the RED. The aim of this paper is to estimate the GHG emission levels and their structure for corn production, including optimal N fertilization, fertilizer types with the lowest possible GHG emission attributed, and with improved agricultural management with reduced tillage or no-tillage cultivation. Finally, the GHG emission savings for the life cycle of corn ethanol are calculated.

Materials and Methods

Data on corn cultivation were gathered from 275 agricultural farms amounting to 3% of total number of farms growing corn for biofuels in Poland. The farms cover a variety of agroclimatic conditions of growing corn in Poland. Data collected include: grain yields (kg ha^{-1}), moisture content (%), applied doses of fertilizers (N, CaO, P_2O_5, K_2O) and pesticide (kg ha^{-1}), and diesel used for field operations (MJ ha^{-1}). The corn stover was estimated according to grain yield. A questionnaire survey was carried out for the industry in order to determine the greenhouse gas emissions from different types of N fertilizers production in Poland[4].

The methodology to calculate GHG emissions of the biofuels chains (RED methodology) was applied using BIOGRACE 4b calculation tool [5]. The agricultural emissions from crop production were estimated with regard to average data on corn cultivation from the 275 agricultural Polish farms surveyed.

BIOGRACE includes estimation of changes in carbon stocks according to the guidelines for the calculation of land carbon stocks based on the methodology of IPPC [6]. Instead of the default soil organic carbon (SOC_{ST}) for High Activity Clay Soils (HACS), which are 50 and 95 t C ha^{-1} for cold temperate, dry and moist climate, respectively, own data were used, which is 41 t C ha^{-1} and is independent on climate zone [7]. With regard to that, the estimated Annual Carbon Stock Change for HACS cultivated with reduced tillage and no tillage, was on average 0.126 and 0.614 t CO_2 ha^{-1} yr^{-1}, respectively. These results were achieved with reference to full tillage cultivation with leaving all harvesting residues in the field, which is the cross compliance requirement for crop growing farms (without animal production), which cover 40% of total number of farms in Poland.

The optimal rates of nitrogen for yields of corn was obtained by boundary line approach. Scatter plot is drawn for yields and nitrogen rates for 275 farm observations. Data points (boundary points) that were located on the outer rim of the data body were chosen. Polynomial and two segment linear regressions were fitted. The lower optimal N fertilizer 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.

Finally, the GHG savings for corn ethanol were calculated in the BIOGRACE, using default values for bioetnanol processing, transport and distribution. Natural gas was chosen as technological fuel in the ethanol processing plant.

Results and Discussion

Planting, growing, cultivation and harvesting of corn in Poland is typical as for other EU countries. However, the data on yield level and agricultural inputs gathered from 275 Polish farms differ from the average data applied for EU [8] (Table 1). The observed farms in Poland growing corn for biofuels applied higher fertilization and achieved much higher yields of corn; these data were used for further calculations. Corn for grain is typically grown in Poland in medium and large-size farms, which aim at maximizing gross margins using higher level of inputs to achieve satisfactory yields. Higher application of P_2O_5 and K_2O is justified in regard with reference to low quality of soils in Poland. The data on corn cultivation applied for the purposes of RED are derived from Global Emission Model for Integrated Systems (GEMIS)[9].

Table 1. Characteristics of corn cultivation in Polish observed 275 farms and EU data.

Parameter	Unit	Poland	EU values [8]
Yield	kg ha^{-1} yr^{-1}	6680	3500
Moisture	%	-	-
Diesel consumption	MJ ha^{-1} yr^{-1}	3149	3600
N	kg ha^{-1} yr^{-1}	124	52
Manure	kg N ha^{-1} yr^{-1}	-	-
P_2O_5	kg ha^{-1} yr^{-1}	63	34.5
K_2O	kg ha^{-1} yr^{-1}	86	25.8
CaO	kg ha^{-1} yr^{-1}	122	-
Pesticide	kg a.s. ha^{-1} yr^{-1}	0.91	2.4
Sowing rate	kg ha^{-1} yr^{-1}	30	-
N_2O field emission	kg N_2O ha^{-1} yr^{-1}	2.80	0.85

The estimated greenhouse gas emission amounted at 35.9 CO_2 eq. MJ^{-1}, which accounts for 19.66 eq. MJ^{-1} with allocation with reference to DDGS (dried distillers grains with soluble). GHG emission structure, including weighted average emission from fertilizers production (3414.2 g CO_2 eq. kg^{-1} N), is dominated by emissions from N fertilizer, both industrial production and application in the field (Fig. 1). It shows the crucial role of N fertilization and its importance concerning possible GHG emission savings in the life cycle of ethanol production. It is possible to optimize the N application doses as well as using fertilizer types with lower emission level with regard to its production process.

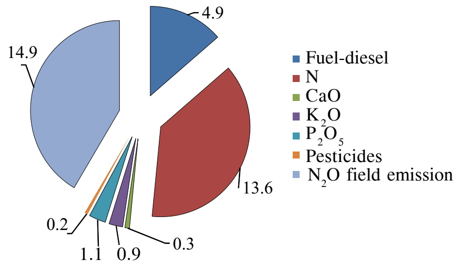

Figure 1. GHG emission structure from corn cultivation for ethanol in Poland (g CO_2 eq. MJ^{-1}).

For the observed 275 farms, optimal N fertilization rate was determined at 120-140 kg N ha^{-1}. With the current average yield 6.68 t ha^{-1} and applied N fertilization, the ethanol processing plants will reach 50% GHG emission savings, unless CAN fertilizer at the rate of 140 kg N ha^{-1} is applied (Tables 2 and 3). Further emission savings would be possible only with improved agricultural management (reduced or no-tillage) which can lead to larger SOC sequestration [6, 10]. Such practices are much advisable for crop growing farms. In further calculations, it was assumed that all the harvesting residue would be left in the field and reduced or no-tillage cultivation would be applied.

Improvement of crop management including reduced tillage and leaving in the field all the crop residue results in the increase of GHG emission savings up to 51-57%, depending on the application of N fertilizer dose and type (Tables 4 and 5). No-tillage cultivation allows to reach GHG emission savings at the level of 62-69%, also depending on the N fertilizer dose and type (Tables 6 and 7). The reduced tillage guarantee GHG emission savings (at least 50%), which are required by the European Commission in ethanol production from 1 January 2018 [2]. However, the required level of GHG emission savings (at least 60%) for biofuels produced in installations starting operation after 1 July 2014 can be achieved only with no-tillage corn cultivation.

Similar study was performed for wheat ethanol in Poland [11]. For Polish farms the GHG emissions related to industrial production of N fertilizer and its application in the field amounted at 76% of total GHG emission for wheat, while for corn it is 79% of total. In both cases, N fertilization has the highest contribution to the total emissions at the agricultural stage of bioethanol production. This was also proved for rapeseed used for biodiesel production [4, 12]. Total agricultural GHG emission for

Table 2. Estimation of GHG emission from corn ethanol production with regard to applied N fertilizers (120 kg N ha^{-1}, full tillage).

Fertilizer	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 savings (%)
Ammonium nitrate 120 kg	3494.5	29.08	15.88	53
UAN (RSM) 120 kg	3080.0	28.15	15.37	54
Saletrzak N(CaMg) 120 kg	4007.6	30.22	16.51	53
Calcium ammonium nitrate (CAN) 120 kg	5012.0	32.47	17.73	51
Multicomponent (NPK) 70 kg, Ammonium nitrate 50 kg	3604.9	29.32	16.01	53

Table 3. Estimation of GHG emission from corn ethanol production with regard to applied N fertilizers (140 kg N ha^{-1}, full tillage).

Fertilizer	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 savings (%)
Ammonium nitrate 140 kg	3494.5	32.31	17.65	51
UAN (RSM) 140 kg	3080.0	31.23	17.06	52
Saletrzak N(CaMg) 140 kg	4007.6	33.65	18.38	50
Calcium ammonium nitrate (CAN) 140 kg	5012.0	36.27	19.81	49
Multicomponent (NPK) 70 kg, Ammonium nitrate 70 kg	3589.2	32.56	17.78	51

Table 4. Estimation of GHG emission from corn ethanol production with regard to applied N fertilizers (120 kg N ha^{-1}, reduced tillage, SOC sequestration at the level of 0.1260 t CO_2 ha^{-1} yr^{-1}).

Fertilizer	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 savings (%)
Ammonium nitrate 120 kg	3494.5	29.08	15.88	56
UAN (RSM) 120 kg	3080.0	28.15	15.37	57
Saletrzak N(CaMg) 120 kg	4007.6	30.22	16.51	55
Calcium ammonium nitrate (CAN) 120 kg	5012.0	32.47	17.73	54
Multicomponent (NPK) 70 kg, Ammonium nitrate 50 kg	3604.9	29.32	16.01	56

Table 5. Estimation of GHG emission from corn ethanol production with regard to applied N fertilizers (140 kg N ha^{-1}, reduced tillage, SOC sequestration at the level of 0.1260 t CO_2 ha^{-1} yr^{-1}).

Fertilizer	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 savings (%)
Ammonium nitrate 140 kg	3494.5	32.31	17.65	54
UAN (RSM) 140 kg	3080.0	31.23	17.06	55
Saletrzak N(CaMg) 140 kg	4007.6	33.65	18.38	53
Calcium ammonium nitrate (CAN) 140 kg	5012.0	36.27	19.81	51
Multicomponent (NPK) 70 kg, Ammonium nitrate 70 kg	3589.2	32.56	17.78	54

Table 6. Estimation of GHG emission from corn ethanol production with regard to applied N fertilizers (120 kg N ha^{-1}, no-tillage, SOC sequestration at the level of 0.6142 t CO_2 ha^{-1} yr^{-1}).

Fertilizer	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 savings (%)
Ammonium nitrate 120 kg	3494.5	29.08	15.88	67
UAN (RSM) 120 kg	3080.0	28.15	15.37	69
Saletrzak N(CaMg) 120 kg	4007.6	30.22	16.51	66
Calcium ammonium nitrate (CAN) 120 kg	5012.0	32.47	17.73	65
Multicomponent (NPK) 70 kg, Ammonium nitrate 50 kg	3604.9	29.32	16.01	67

Table 7. Estimation of GHG emission from corn ethanol production with regard to applied N fertilizers (140 kg N ha^{-1}, no-tillage, SOC sequestration at the level of 0.6142 t CO_2 ha^{-1} yr^{-1}).

Fertilizer	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 savings (%)
Ammonium nitrate 140 kg	3494.5	32.31	17.65	65
UAN (RSM) 140 kg	3080.0	31.23	17.06	66
Saletrzak N(CaMg) 140 kg	4007.6	33.65	18.38	64
Calcium ammonium nitrate (CAN) 140 kg	5012.0	36.27	19.81	62
Multicomponent (NPK) 70 kg, Ammonium nitrate 70 kg	3589.2	32.56	17.78	65

wheat ethanol production (with allocation for DDGS) was estimated at the range of 18.70-30.20 CO_2 eq. MJ^{-1} for the optimal fertilisation (90-160 kg N ha^{-1}). For corn ethanol, it is 15.37-19.81 CO_2 eq. MJ^{-1} for the optimal fertilisation (120-140 kg N ha^{-1}). It shows that corn ethanol has a better performance in terms of agricultural emissions compared to wheat ethanol, which is much related to the higher yield of corn per land unit.

The required emission savings (from 1 January 2018) at the level of at least 50% (for installations starting operation before 1 July 2014) can be achieved by corn ethanol for the optimal N fertilization range and conventional tillage, while for wheat it is possible only for the low range of the optimal fertilization (90 kg N ha^{-1}). Appling reduced tillage or no-tillage, both for corn and wheat ethanol, results in organic soil carbon sequestration, which leads to reduced GHG emissions. The relative effect of these practices counted per MJ of ethanol produced is more evident for corn ethanol than for wheat ethanol. For new ethanol installations starting operation after 1 July 2014, the required GHG emission savings in life cycle of ethanol would be at least 60%. For wheat ethanol, this could be achieved only for no-tillage cultivation and N fertilization of 90 kg N ha^{-1}. For corn, no-tillage crop growing would be also required, but much higher N fertilization would be possible (120-140 kg N ha^{-1}). If new ethanol plants opened after 1 July 2014 prefer to use wheat and corn raw materials from conventional cultivation, the possibility to reach the mandatory GHG savings still may come from the substitution the fossil technological fuel used in the plant with renewable energy.

Conclusions

The conventional cultivation of corn, which is typical for Polish farms, guarantee that the corn based ethanol fulfill the required sustainability standard in terms of greenhouse gas emission savings at the current level of at least 35%. The future required life cycle GHG emission savings of 50-60% for corn based ethanol production can be achieved in Poland with improvement in the crop management. These include optimization of N fertilization doses, selection of N fertilizer assortment with the lowest industrial GHG emission as well as application of reduced and no-tillage crop cultivation. These practices are more efficient for corn than wheat in terms of GHG emission mitigation at agricultural stage of ethanol production.

Acknowledgements

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