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Carbon Footprint of Rapeseed in Conventional Farming: Case Study of Large-Sized Farms in Wielkopolska Region (Poland)

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ABSTRACT

At present, Poland is the 7th top rapeseed producing country in the world. As rapeseed is an input-intensive crop, concern arises that increasing areas its increased production could hinder the efforts to limit greenhouse gas (GHG) emissions from crop fields. The aim of the study was to identify the carbon footprint performance of rapeseed production for conventional cultivation practices of large-sized farms, considered as most representative for the rapeseed production in the Wielkopolska region (Poland). Analysis is based on the case study of two large-area farms. To investigate GHG emission intensity, carbon footprint for rapeseed was calculated for the years 2011-2013. Assessment was undertaken along the life cycle from cradle to farm gate. Both specific data, collected on the farms, and literature data for upstream processes for life cycle inventory were used. Overall, the calculated carbon footprint of rapeseed production was around 794 kg CO_2 eq. Mg^{-1}. The analysis revealed that the fertilizer operation contributed most to the carbon footprint, with a share of about 78%. After the fertilization process was examined separately, using the life cycle approach, it was shown that GHG emissions from fields was the most important factor influencing GHG emission related to fertilization activity. Production of nitrogen fertilizers was the second important hot-spot which generated GHG emissions in the life cycle assessment of fertilizers. It is concluded that the carbon footprint assessment done for the rapeseed production process in the studied farms, considering their typical cultivation practices and defined production scale, could be of referential value for the carbon footprint estimations in varying rapeseed production options from a local to an international level.

Key Words: Carbon footprint, life cycle assessment, rapeseed, agriculture, environment

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INTRODUCTION

Over the last fifteen years, there has been a steady increase in the area of rapeseed over the world. The global acreage of this crop is about 36 million ha. It is currently the third most produced oil plant in the world, after soybean and palm oil, with respect to the vegetable oil production of over 72 million megagrams (Mg), (FAOSTAT, 2015). The growing demand for rapeseed is explained mainly by three factors: the health and nutritional properties of rapeseed oil, its heat stability and relatively high oil yield per unit area of cultivation (Lin *et al*., 2013, Tahir *et al*., 2012, Tutunea, 2013).

Adoption of the renewable energy strategy has triggered the development of rapeseed production in the European Union (EU). In the accepted road map for renewable energies in the EU, it established a target of 10% share of biofuel in overall consumption of petrol and diesel for transport by 2020 (Communication …, 2007). The current production of rapeseed oil in EU meets about 65% of the total demand for biodiesel. Favorable climatic conditions and adequate soil quality in the EU for the cultivation of rapeseed are additional incentives for the expansion of its growing areas. In Poland, the area share of rapeseed in cropping structure increased from 5.4% to 7.6% between the periods 2005-2007 and 2011-2013, but in the absence of improvement in the yield per hectare (2.65 Mg ha^{-1} vs. 2.58 Mg ha^{-1}). Currently, increasing the acreage of rapeseed takes place mainly at the expense of reducing the area of cereals and root crops. By changes in the relative relationships between the acreages of cereals, root crops and rapeseed, it is expected that the size of GHG emission will vary in response to different tillage operations and inputs requirements of these plants.

The use of large amounts of mineral substances and industrial materials increasing productivity can cause excessive GHG emissions to the environment. These emissions are an essential part of the environmental impact of the rapeseed production defined by the so-called "Carbon Footprint." It is determined by using the Life Cycle Assessment (LCA) approach, according to which GHG emissions throughout the whole production chain are embraced (Dong *et al*., 2013, Shrestha *et al*., 2014).

Although rapeseed has become in recent years a plant of great economic importance in Polish agriculture, there is still a lack of research regarding its carbon footprint that could take into account regional differences and technological variability of production systems. As literature results show, there is a possibility of reducing the "carbon footprint" of rapeseed-based products through the proper use of agricultural practices (Shrestha *et al*., 2014).

The core aim of this study was to determine the size of the carbon footprint of rapeseed grown in the typical cultivation system of two large-size farms, considered to be the most representative production type of this crop in Wielkopolska. Secondary objectives were used to indicate the diversification of farm-level agricultural operations in relation to the value of the carbon footprint and to identify places in the rapeseed production system with the largest expected effects of reducing the carbon footprint.

MATERIALS AND METHODS

The study was conducted during the period 2011-2013. The research places included were two farms, Trzebiny (farm 1) and Dlugie Stare (farm 2) belonging to the Dlugie Stare Agricultural Company Ltd., a subsidiary of the state Treasury. The company is located in south-western part of the Wielkopolska region. It is characterized by the presence of both crop and dairy production (milking cows and breeding of replacement heifers). In fact, it is numbered among small, elite group of farm enterprises of the State Treasury, which are responsible for the creation and the introduction of the technological progress in agriculture. Agricultural practices are tailored to the current recommendations of the integrated production methods and integrated pest management. In both farms, winter rape is grown in two cropping rotations. Crop sequence in the first rotation pattern is maize, winter cereal, winter rape, winter cereal, and in the second one - manured sugar beets, winter wheat, winter rape, winter wheat. All cereal straw together with rape one is removed from the fields and used as bedding material for livestock. The farms have a similar area of about 500 hectares of agricultural land. Farm descriptions are presented in more detail in Table 1.

Table 1: Farms characteristics (averages from the years 2011-2013 ± standard deviation)

Specification	Farm 1	Farm 2
Usable agricultural area (ha)	492.3	516.2
Soil quality index of arable soils	0.67	1.15
NPK fertilization (kg)	118.1 ±43.6	103.0 ±14.7
Stocking rate (LSU)	0.69 ±0.01	0.72 ±0.03
Cereal yield (Mg ha^{-1})	5.64 ±0.51	6.58 ±0.23
Rapeseed (Mg ha^{-1})	3.64±0.36	2.62±0.13

Special farm record sheets were prepared to collect data from agronomic activities. Each sheet had been assigned to the individual unit process, distinguishing between input and output from the given process. The forms were filled in regularly according to a schedule of field works. The data in the forms were referenced both to a single plant and a single field. They included field characteristics, type and duration of technological operations, input materials for producing the crop: fertilizers, pesticides, agricultural machinery (type of machine, total machine weight, work time spends for the cultivation of a given crop, a lifetime of the machine), fuel, engine oil, electricity. Because of the biological properties of the agricultural production and the interactions of manufacturing processes with the environmental factors, the massive sets of data had to be collected over a period of 3 years that were subsequently aggregated. Additional sources of data were: the technical documentation of machines, the accounting documents and the interviews with production managers. Whereas the data for earlier stages of the processes (industrial inputs for production), preceding the production phase on the farm, were collected from Agribalyse® database and literature (Colomb *et al.* 2013, IPCC, 2006a, Audsley *et al.*, 2009).

The carbon footprint is expressed in the general form as a sum of products of the greenhouse effect for a given substance and size of the emissions of this substance. A methodology for calculating the carbon footprint was adopted in the PAS 2050 standard (BSI, 2011). The carbon footprint, calculated according to this methodology, includes both direct emissions and indirect, which arise throughout the whole product life cycle. Greenhouse gas emissions in agriculture generally refer to the three gases: CO_2, N_2O and CH_4 due to their large amounts emitted in the course of the long chain of agricultural production. The carbon footprint analysis was performed according to the LCA methodology, i.e. from the extraction of raw materials through the main production stage, up to the waste disposal (Milà i Canals *et al.*, 2011). Research methodology complying to the formal requirements of LCA included the analytical framework composed of four phases: the statement of purpose and scope, the analysis of a set of inputs and outputs (life cycle inventory), the life cycle impact assessment and the interpretation (Brentrup *et al.*, 2004).

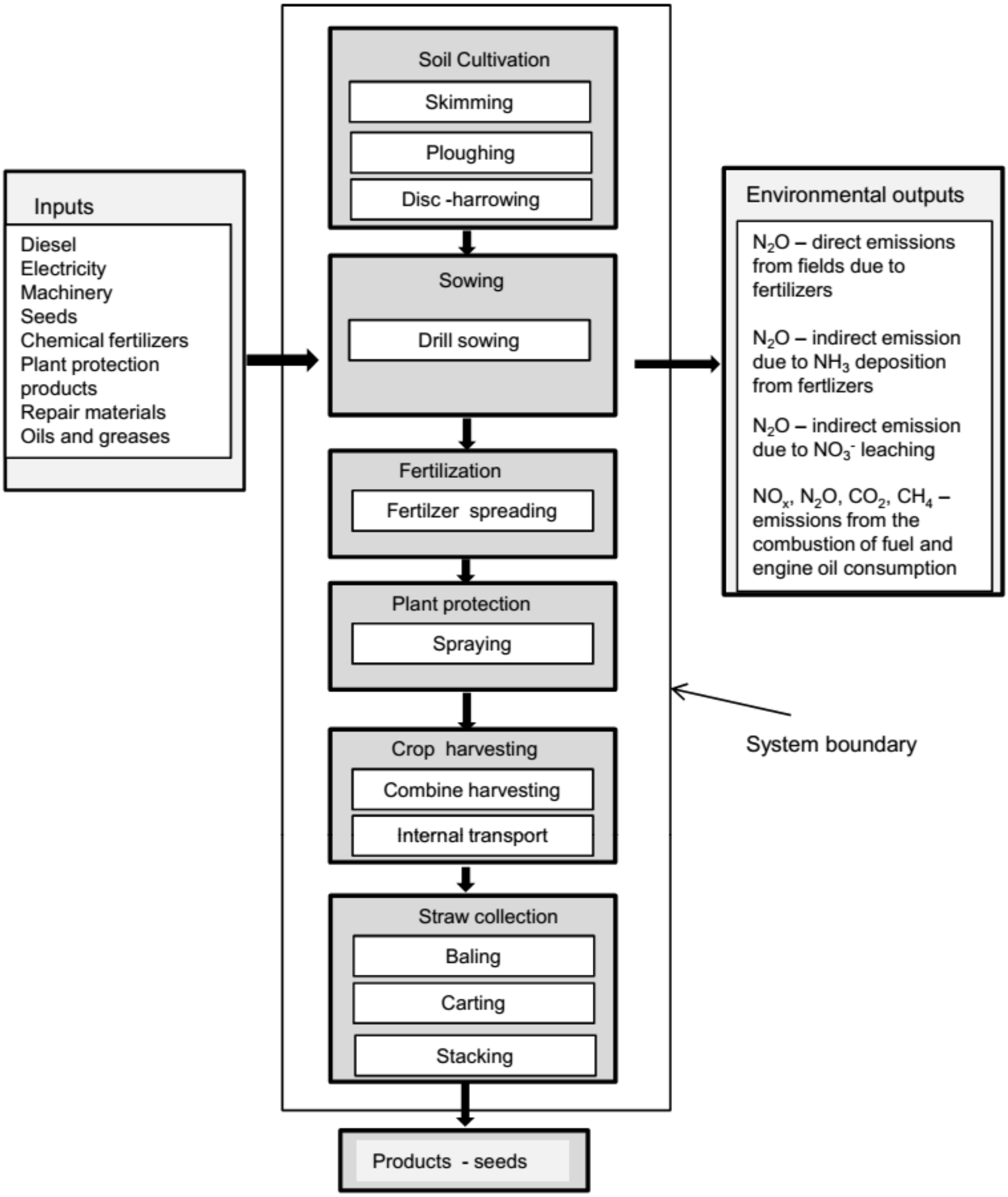

Figure 1: System boundary, inputs and outputs in the system of rapeseed production

The scope of the analysis (phase 1): the majority of data for the production site, within the life cycle of rapeseed, are based on locally specific information and come from a defined place in the Wielkopolska region. A part of production materials (raw materials and substances) have been manufactured in the country. Farm equipment has been purchased from a local dealer network. They are mostly imported from the EU. Rape seed is regularly sold to the oil industry facility located in the Wielkopolska region. The major area of rapeseed use is the production of rapeseed oil. That is why it was decided to relate the function of rapeseed production to this aspect and express it as the production of seeds with standard quality parameters, low humidity and a high degree of purity, which all together ensure a high yield of food oil. The range of technological conditions characterized the typical, modern technology of production with regular use ploughing operations. The functional unit was defined as one Mg of rapeseed grain with the moisture content not exceeding 6%. LCA was carried out from the “cradle- to-farm gate" (i.e. t he width of the system). Rapeseed after the harvest has a function of semi-product to be used later in core processes for various purposes in the industry. For such type of product, there are no clearly established phases of the use and waste disposal, so it was more appropriate to carry out the analysis up to the stage of the “farm gate” (Figure 1). As there were no co-products in the production system, it was not necessary to use the allocation procedure for the inputs and outputs.

Analysis of the inputs and outputs in the inventory (phase 2): In this phase, the key measure was to prepare the Life Cycle Inventory (LCI) model, consisting of a set of inputs and outputs for the inventory. Its primary objective was to obtain a LCI table, listing the input and output with reference to the functional unit.

Data on GHG emission included three areas: a) direct emissions (CO_2, CH_4, N_2O) produced during the combustion of fuel by tractors and self-propelled machines involved in all technological operations in the rapeseed cultivation, b) direct and indirect emissions of N_2O from the fields of rapeseed due to the use of mineral fertilizers, c) background emissions, expressed in CO_2 equivalent, related to the production of fertilizers, pesticides, use of electricity and tractors, as well as agricultural machinery. Early emissions occurred in the industry are appropriate for the initial stage of the life cycle of rapeseed that is formally defined as the upstream stage. These emissions are related to the supply chain of agricultural means of production, and they do not belong directly to the core module, which is the field cultivation of rapeseed.

Direct and indirect emissions of N_2O associated with the use of mineral fertilizers were calculated based upon the IPCC methodology (IPCC, 2006a) and EMEP/EEA guidebook (EMEP/EEA, 2013). For the calculation of greenhouse gas emissions generated by various tractors during the field works, the emission factors for different types of fuels and engine technologies given in the EMEP/CORINAIR (2002) were used. The emissions assigned to a production stage and a distribution of mineral fertilizers was calculated using the quantity of applied fertilizers and emission factors for fertilizers type. According to the literature sources they were, respectively, 2.792 kg CO_2 eq. kg^{-1} N, 0.738 kg of CO_2 eq. kg^{-1} P_2O_5 and 0.352 kg CO_2 eq. kg^{-1} K_2O (GHGenius, 2010). The two-step calculation procedure was used to estimate the greenhouse gas emissions in the production, packaging and distribution of pesticides. In the first step the amounts of herbicides, fungicides and insecticides were converted to units of cumulated energy consumption according to the conversion factors in the MJ kg^{-1} a.i. In the next step, the GHG emissions were determined assuming the emission ratio, related to the energy consumption for a production of pesticides, equal to 0.069 kg CO_2 eq. MJ^{-1} (Audsley *et al.*, 2009). In the same way, the indirect GHG emissions assigned to a production of agricultural machinery were calculated. For a rapeseed crop cultivation, the first estimation of agricultural machinery consumption in kg h^{-1} of its work was done in relation to the whole life time of the machines and then converted into MJ of cumulated energy, using energy conversion factors (Harasim, 2002). The weight of the spare parts was set at the level equal to 30% of the mass of tractors. Repair materials accounted for 4% of spare parts. GHG emissions for the energy consumed in the production of machinery was calculated based on the MJ of energy used and the default values of the coefficients of GHG emissions in the industrial sector for the level of tier 1, without considering the differences in national emissions (IPCC, 2006b).

Life cycle impact assessment (phase 3:) One impact category – global warming potential (GWP) was subjected into this phase of LCA analysis which was synonymous with the carbon footprint estimation. For the evaluation of this impact, universally accepted model of the IPCC was applied (IPCC, 2006a). On the basis of the list of elements (available from the developed LCI table) results of GHG emissions were assigned to this category. In this paper, calculations of GWP associated with the production of one Mg of rapeseed have been presented. Also, for the purpose of extending a scope of interpretation of the impact assessment of rapeseed, results analysis have been referenced to another functional unit of one ha of rapeseed cultivation.

RESULTS AND DISCUSSION

The calculated mean value of the carbon footprint of rapeseed in the studied farms, in relation to the functional unit, was 794.2 kg CO_2 eq. Mg^{-1} (Table 2). There were noticeable differences in the GHG emissions between farms. The emissions from farm 1 were lower by 19% compared to the second one. Among the modifying factors of carbon footprint values in a direct way, crop productivity was likely the most important one and yet an intermediate factor, which could be related to soil quality, determining the yield potential of crops with high nutritional requirements. It must be assumed that the possible tiny technology gaps in the rapeseed cultivation were of secondary importance in influencing the carbon footprint because both farms operate within one agricultural enterprise. They had a similar set of machinery, and they also used similar tillage technology and harvest management.

Table 2: The carbon footprint per functional unit and per unit area of rape cultivation in the analyzed farms (averages for the periods 2011-2013)

Technological operations	kg CO_2 eq. Mg^{-1}		kg CO_2 eq. ha^{-1}		kg CO_2 eq. Mg^{-1}	kg CO_2 eq. ha^{-1}
	Farm 1	Farm 2	Farm 1	Farm 2	Mean	
Cultivation and seeding	58.9	85.5	214.4	223.9	72.2	219.2
Fertilization	567.0	680.1	2063.9	1781.9	623.6	1922.9
Crop protection	37.7	61.9	137.1	162.2	49.8	149.7
Crop harvesting	43.6	53.9	158.6	141.1	48.7	149.9
Total	707.1	881.3	2574.0	2309.1	794.2	2441.6

The magnitudes of the carbon footprint in the studied farms are comparable with the Chilean results. In the Araucania region concentrating on the rapeseed cultivation in Chile, the carbon footprint associated with this crop was 820 kg CO_2 eq. Mg^{-1} seeds, in the conditions of conventional plough system (Iriarte *et al.*, 2010). On the other hand, oilseed crops (rapeseed and mustard) grown in

Saskatchewan, Canada, had the carbon footprint of an average of about 734 kg CO_2 eq. Mg^{-1} (Gan *et al.*, 2012). Lower emissions of GHG gases were explained by the use of zero-tillage technology and the lower N fertilization. In Finland in the average production conditions, covered by the national agricultural database, the carbon footprint for rapeseed was 1480 kg CO_2 eq. Mg^{-1} (Saarinen *et al.*, 2012). Probably a low productivity of plants resulted from the harsh climatic conditions and on an average of less fertile soils in Finland is a persistent barrier limiting the production potential that cannot be easily removed by the technological progress. Currently, among the experts in the GHG emission problems there is a perception of a need for the comparative analysis of the carbon footprint of plant materials that originate from different cultivation systems and different modes of production management. It is widely accepted that the carbon footprint can be an objective instrument for assessing the reduction effects of GHG emissions from agriculture, obtained through a variety of innovative technological solutions and environmental policies aimed at lowering the carbon emissions (Gan *et al.*, 2011).

Mineral fertilization, from within the distinguished technological operations, had the greatest impact on the GWP (Table 2). In absolute terms, fertilization generated GHG emission of 623.6 kg CO_2 eq. per functional unit, which corresponded to the emissions of 1922.9 kg CO_2 eq. in relation to 1 ha area of rapeseed. Higher GHG emission expressed per unit area of 1 hectare in farm 1 than in farm 2 has not been reflected in the emission referred to the functional unit of 1 ton because of the higher, as mentioned earlier, rapeseed productivity in farm 1. On average, mineral fertilization contributed over 78% of the total carbon footprint (Figure 2). According to Iriarte *et al.* (2010) the impact of fertilization was even higher, exceeding 80%. In our study, soil cultivation together with sowing was the second largest component of the carbon footprint, accounting only to 9% of the total value of carbon footprint. Other technological operations exerted even less impact on the carbon footprint. Their share ranged from 5.3% to 7.0% in both farms.

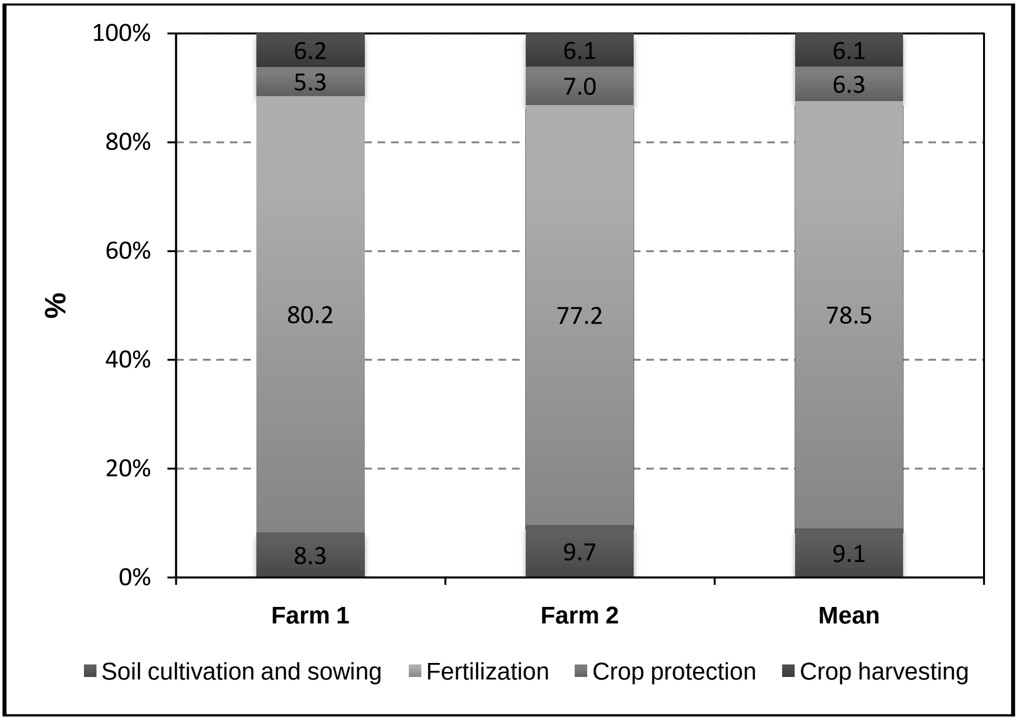

Figure 2: Percentage share of different technological operations in the carbon footprint for rapeseed (averages for the period 2011-2013, for 100% - total carbon footprint)

The results indicate that the direct and indirect GHG emissions from fields, especially N_2O, are of great importance in the whole cycle of fertilizer use in the rapeseed production (Figure 3). The average GHG emission from fields was approximately 391 kg of CO_2 eq.

Mg^{-1} seeds, which accounted for about 63% of the total GHG emission. In the total emission load from fertilization, 29% of that emission was attributed to a process of fertilizer production. Nearly six times lower GHG emissions occurred in the production of phosphate and potassium fertilizers as compared to nitrogen fertilizers. Emissions associated with fuel consumption and the ones attributed to the use of tractors and machinery in the field work and grain handling were of marginal importance. Altogether they accounted for less than 4% of the total emissions linked to a fertilization process.

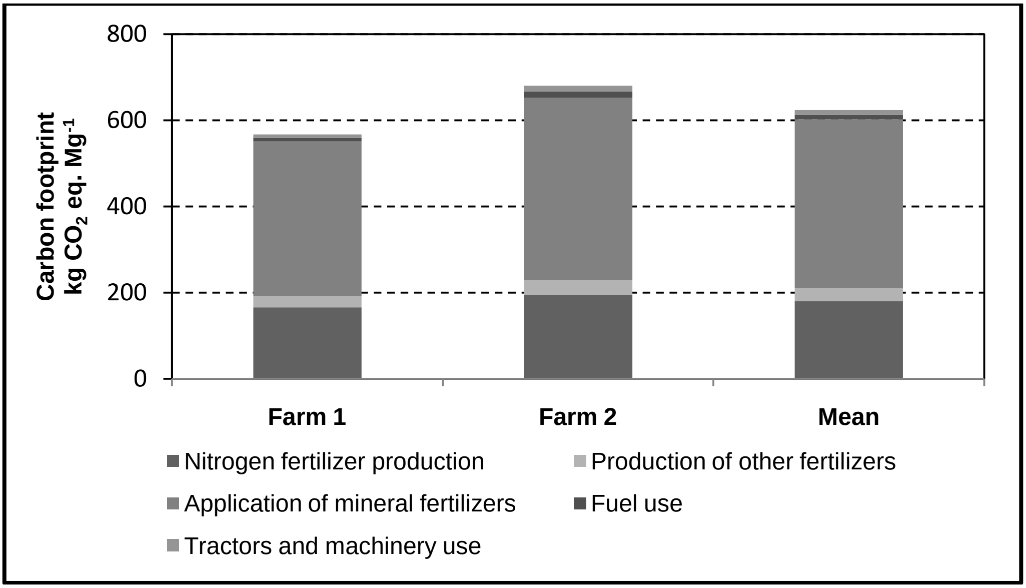

Figure 3: The components of the carbon footprint for rapeseed associated with the process of fertilization in the analyzed farms

Emissions from fields associated with fertilization in the studied farms were 2-fold higher than for rapeseed and mustard grown in Canadian conditions (Gan *et al.*, 2012). The plausible reason for the marked discrepancies in the structure of emissions from fertilizers was different technology of their application. In Canada, nitrogen fertilizer was applied in a one-time dose simultaneously with sowing, while in the studied farms fertilizers were split into several applications and they were not integrated with sowing. Modification of fertilizing practices through the aggregation with sowing may contribute to a possible reduction of the rapeseed carbon footprint in the future not only in the examined farms, but it could have a wider extent within the Wielkopolska region and also throughout the country. In field experiments with varying fertilization levels, it turned out that the magnitude of the carbon footprint was a function of the nitrogen fertilizer rates (Gan *et al.*, 2012) . Within the range of nitrogen rates between 180 and 200 kg ha^{-1}, the carbon footprint for the Canadian studies was approximately 1000 kg CO_2 eq. Mg^{-1} grain, while in the surveyed farms with a similar level of fertilization was lower by more than 200 kg of CO_2 eq. Mg^{-1}. GHG intensity accompanying rapeseed production on farms should be considered moderate despite the use of the plough system and relatively high doses of nitrogen fertilization. Presently available possibilities of introducing less energy intensive methods, like zero-tillage, into the rapeseed cultivation indicate to an unused potential of further reduction in GHG emissions without compromising on productivity.

CONCLUSIONS

The broad and diverse nature of the data needed to analyze the carbon footprint of the products in general from the life cycle perspective, which in our study concerned the rapeseed, was a demanding task. Taking into account the specificity of the production process required strict compliance with the formal requirements of IPCC methods to ensure the reliability and comparability of the results. An important step in the initial phase of our analysis of the carbon footprint was to adjust a set of data in the inventory table for the rapeseed production process to the boundary of its system.

The results of the carbon footprint analysis for rapeseed in the analyzed farms, due to the still used conventional technology and the scale of production, may serve as reference values for the assessment of GHG emission intensity for similar types of field operations both in the region, and in the country. Analysis of GHG emissions through carbon footprinting is gaining in importance due to the inclusion of agriculture to the EU's emission reduction programs because such analysis is regarded to be an important tool for the quantitative evaluation of emission changes resulting from the use of different mitigation measures in agricultural production.

Mineral fertilization process contributed highly to the carbon footprint impact. The effect of other agronomical operations on the carbon footprint was many times lower than for fertilization. At present, there are several possibilities for further reduction of GHG emissions by taking action towards improvements in the efficiency of fertilizer use and production. Available technological options in this area include, among others: proper timing and application methods, optimization of fertilizer usage, new formulations of fertilizers. Further benefits in reducing the carbon footprint can be obtained by machinery setting and simplified tillage operations.

The carbon footprint was calculated for the system boundary including the stages from "cradle to farm gate". The data obtained are indispensable for extending the carbon footprint analysis by the processing stage in the food and non-food agro-industry using rapeseed as a raw material, and further – up to the stage of product use and its disposal. Information acquired during the field cultivation of rapeseed should be an important part of the inventory database for any industrial processes using this crop as a raw material. Only that degree of data integration will enable a complete assessment of the carbon footprint of rapeseed-based products after the emission changes driven by technological and market development.

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