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INFLUENCE OF FARMING SYSTEM ON GREENHOUSE GAS EMISSIONS WITHIN CEREAL CULTIVATION

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Abstract

The emissions of greenhouse gases (GHG) from anthropogenic activities have still been a topical and much-discussed issue. In farming, room for reducing GHG emissions may also be available in crop farming. The measures aimed at the mitigation of GHG emissions may include a change in the farming system or partial switch to more extensive farming methods, including organic farming. The life cycle of oat, rye, wheat and spelt wheat cultivation in conventional and organic farming systems in the conditions of Central Europe was evaluated by LCA method, impact category: climate. The results clearly show that there are considerable differences between conventional and organic farming systems in individual subcategories of the farm phase of the production of cereals. The CO_{2e} emissions produced in the cultivation of the monitored cereals are lower in organic farming systems, both when converted to an area unit and when converted to a production unit.

Key words: cereals, emissions, greenhouse gases, LCA, organic farming

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1. Introduction

In the course of the 20th century, the population grew from 1.6 to 6.1 billion (Lutz et al., 2013). This results in a steady rise in the consumption of natural sources and agricultural products (Foley et al., 2011). Since the population growth continues very rapidly, and the consumption of meat or other animal husbandry products as well as the consumption of energy in agriculture and food industry are on the increase, it cannot be expected that the trend of the growing environmental load would reverse spontaneously in the near future (Goodland, 1997; Schau and Fet, 2008). The global GHG emissions from agriculture amount to 5.1 – 6.1 billion tons of CO_2 equivalent (Niggli et al., 2011) [CO_{2e} in further text]. Baumert et al. (2005) determine the shares of GHG (CO_2, N_2O and CH_4) emissions produced in various branches of human activities. According to their findings agriculture accounted for a 13.5% share of the anthropogenic emissions in 2000. Friel et al. (2009) also claim that the share of agriculture in the global emissions is 10-12%, and an increase by half of those values can be expected to take place by 2030 (Smith et al., 2007).

According to IPCC report (IPPC, 2007) the share of agricultural production in the anthropogenic production of GHG emissions is 14%, and this share differs in various countries according to the intensity of the agricultural production. In general, carbon dioxide (CO_2) is the most important GHG generated as a result of human activity. It accounts for 82% of

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all GHG emissions produced by the 27 EU member states, accounting for a 55% share in the total warming of all man-emitted gases (IPCC, 2014; Quashing, 2016). Agriculture is also a significant emission producer in the EU according to Brandt and Svendsen (2011). In the EU-27, the total share of GHG emissions from agriculture was 10.1% in 2011 (Pendolovska et al., 2013). Similar values can also be found in the UNFCCC report (2011), according to which this share amounted to 10.2% in 2009 in the EU-15. Therefore, ways to reduce greenhouse gas emissions are also searched for in agriculture.

In addition to animal husbandry, GHG emission savings may also be found in crop production, especially due to the large areal extent. Activities in the field of land use change, fertilizer use and production, fossil fuel burning and agricultural waste burning are the main sources of GHG emissions in the agricultural sector and they are presented as sources of CO_2 from agricultural production for example by (Nimkar et al., 2015). Another significant gas is N_2O, which is emitted in terms of production and utilization of nitrogen fertilizers and due to volatilization during various agricultural activities (Rees et al., 2013; Sutton et al., 2011). Last but not least, agricultural GHGs are associated with animal husbandry, especially beef cattle breeding and CH_4 production (Bellarby et al., 2013). The room for such measures is available in both non-food production, e.g. in the cultivation of energy crops (Bernas et al., 2016), and food production.

The most commonly grown groups of crops include cereals, which are very significant in terms of both the human nutrition and the size of the areas where they are grown (e.g. in the Czech Republic, the size of cereal fields constitutes more than half of the total arable land and, on a worldwide basis, wheat is one of the four crops that cover approximately 80% of the caloric consumption of mankind) (Šarapatka et al., 2008). This is also a reason why cereals constitute one of main groups in crop production, in respect of which it is possible to take mitigation measures. Cultivation of cereals in the conventional and organic farming system has its own specifics, which result in particular from a different approach to the protection and nutrition of plants in these systems of farming. Absence, or a very low rate of use of agrochemicals in organic farming often leads to an increase in the number of agrotechnical operations serving to protect plants; in terms of plant nutrition, in addition to the application of organic fertilizers, great emphasis is placed on proper selection of crops and securing of nitrogen from other sources (e.g. more frequent cultivation of leguminous plants).

The measures leading to a mitigation of GHG emissions may also include a change of the farming system or a partial switch to more extensive farming methods, including organic farming. Niggli et al. (2011) state that intensive crop production (often based on monocultures and high productivity) largely depends on external inputs, such as mineral fertilizers and chemical plant protection products. Sustainable farming procedures, such as organic farming, greatly reduce such dependence on inputs. As presented by Lal (2004a), a system sustainability can be evaluated based on inputs and outputs and their conversion to CO_{2e}. The American research “Rodale Institute's Farming Systems Trial”, which was focused on long-term comparison of the effects of organic and conventional farming, confirms that introduction of organic farming in the whole USA would reduce CO_2 emissions by as much as a fourth due to the increased carbon sequestration in soil (LaSalle and Hepperly, 2008). In order to be able to assess the efficiency of a change of the farming system, it is necessary to quantify the exact environmental load or rather the production of GHG in the given farming systems.

There are several suitable methods used for the assessment of environmental impacts of agricultural activities (Finnveden and Moberg, 2005), such as the Life Cycle Assessment (LCA), Ecological Footprint (EF) or Emergy Analysis (EA – analysis of direct and indirect energy flows) (Thomassen and De Boer, 2005; Van Der Werf and Petit, 2002). Cambria et al. (2016) or Ng et al. (2016) also present a suitable method for evaluating agricultural activities. Moreover, LCA, as one of the few tools, offers a comprehensive approach to the evaluation of environmental impacts at present (Kim and Dale, 2005; Nelson and Robertson, 2008; Requena et al., 2011; Wagner et al., 1998). LCA is also a very valuable tool due to its ability to include and compare various farming systems, their individual processes and products and most of their environmental impacts (Charles et al., 2006; Haas et al., 2000; Haas et al., 2001).

The aim of this paper is to quantify and assess the environmental aspects of growing of major cereal species in the conditions of the Czech Republic and Central Europe within the conventional and organic farming system, especially in terms of the impact of organic and conventional agriculture on greenhouse gas emissions.

2. Material and methods

The life cycle of growing oat, rye, wheat and spelt wheat in the conditions of Central Europe was modelled in the software SIMA Pro (method ReCiPe Midpoint (H) Europe) in accordance to the standards ČSN EN ISO 14040 (ISO, 2006a) and ČSN EN ISO 14044 (ISO, 2006b). As a functional unit, 1 kg of grain was used. The output was the yield per hectare, the inputs included technological operations, seed quantity, fertilizer quantity, and plant protection products. The LCA framework includes the farm phase (field emissions, seeds and seedlings, fertilizers, pesticides, and agrotechnical operations).

In addition to the emissions produced from the above stated inputs, there are also field emissions (N_2O emissions) released after the application of nitrogen fertilizers. They are quantified by the methods described in IPCC (*Intergovernmental Panel on Climate Change*) (De Klein et al., 2006).

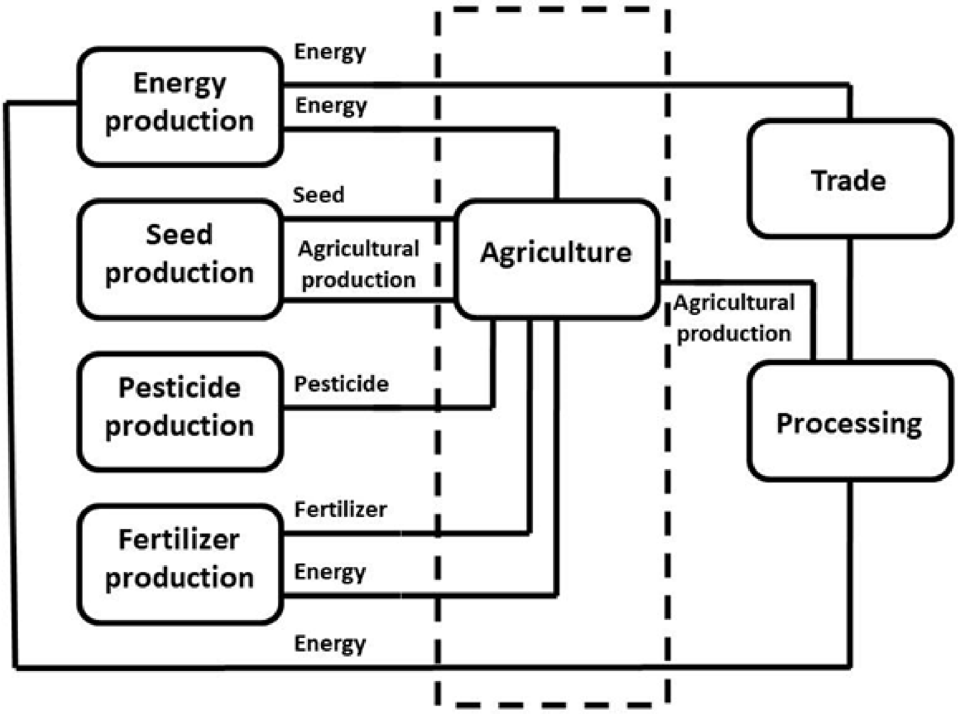

Fig. 1. Determination of the system boundaries – LCA framework

The greenhouse gases were converted to CO_{2e} based on the formula (Eq. 1):

$$CO_{2e} = 1 \times CO_2 = 23 \times CH_4 = 298 \times N_2O \qquad (1)$$

The calculation of the emission load used the values obtained from the experimental cultivation of cereals in small experimental plots of the Faculty of Agriculture of the University of South Bohemia in České Budějovice (experiments were based both on an experimental plot certified in organic farming and on an experimental plot with conventional farming system) and referential operational and pilot stations, supplemented by the yield parameters from the selected set of 50 farms in the Czech Republic, the set comprising of 25 farms operating in organic farming and 25 farms operating in conventional farming system. The number of farms in the set was influenced by the total number of farms operating in organic farming system focusing on the cultivation of cereals and by the availability of the data from them. The basic data from the farms were supplemented from the Ecoinvent database (Ecoinvent, 2010).

The input data from the Ecoinvent database (2010) were adjusted to the farming conditions in the Czech Republic. The adjustments concerned mainly fuel consumption in individual agrotechnical operations. Based on the data from the selected set of farms, the most common agrotechnical procedures used in the cultivation of the monitored cereals in conventional and organic farming systems were identified. These procedures are a sequence of the most commonly used agrotechnical operations that are being carried out during cultivation, the most common agrotechnical line being developed for each monitored cereal as well as farming system. Based on these operations, the technological chains of operations used for the calculation of greenhouse gas emissions were made up.

Wheat, rye and oat were evaluated in conventional and organic farming systems; in the Czech Republic, spelt wheat is grown almost solely in organic farming systems. The average yields in the evaluated selected set grown in a conventional farming system amounted to 5.6 t/ha for wheat, 3.7 t/ha for oat and 4.0 t/ha for rye, while the average yields of the crops grown in an organic farming system amounted to 3.5 t/ha for wheat, 2.6 t/ha for oat, 2.9 t/ha for rye and 3.3 t/ha for spelt wheat.

3. Results and discussion

In the Czech Republic, cereals are the most widely grown group of crops, and are grown on approximately 50 % of arable land (Capouchová et al., 2012; Konvalina et al., 2014; Moudrý and Konvalina, 2007; Stehno et al., 2010). Given the size of the area on which they are grown, they also rank among the crops significant in terms of a possible reduction of anthropogenic emissions of greenhouse gases.

In both organic and conventional farming systems, the growing of cereals have certain specifics leading to different environmental loads or rather different greenhouse gas emissions. The greenhouse gas emissions within the production of cereals vary in different regions due to differences in species, climatic conditions, soil conditions and production system (Barton et al., 2008).

Table 1. The yield parameters of the monitored cereals

Parameter	***Unit***	***Wheat***		***Rye***		***Oat***		***Spelt wheat***
		Conv.	***Organic***	***Conv.***	***Organic***	***Conv.***	***Organic***	***Organic***
average	t/ha	5.6	3.5	4.0	2.9	3.7	2.6	3.3
SD	t/ha	1.1	0.6	1.0	0.9	0.6	0.7	0.6
CV	%	19.9	18.6	24.6	32.3	17.0	27.1	17.0
Median	t/ha	5.8	3.5	4.1	2.7	3.7	2.6	3.4
Mode	t/ha	6.6	3.6	5.3	2.4	4.2	2.6	3.7

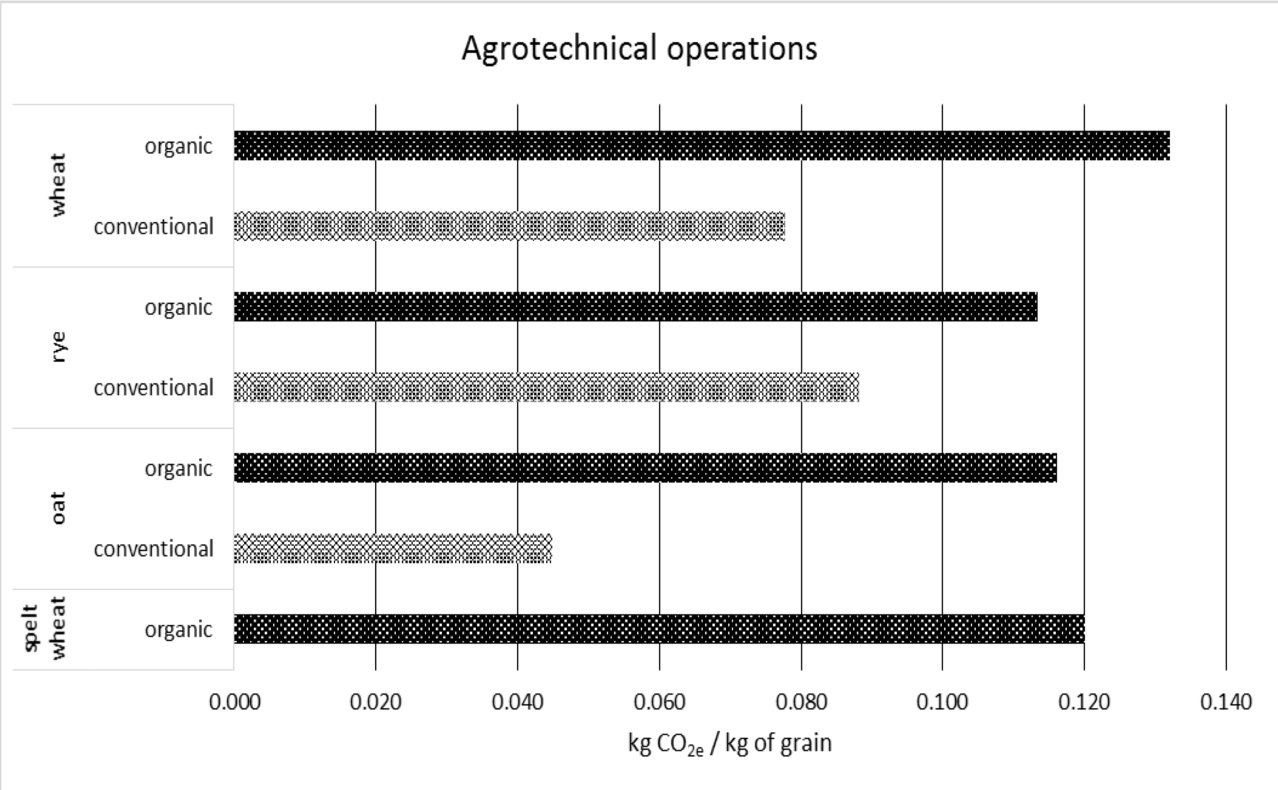

Fig. 2. GHG emissions from the basic category "agrotechnical operations"

The yield of individual crops is essential for the conversion of the emission load per unit of production. Table 1 summarizes the yield parameters of the monitored cereals in the conventional and organic farming system; the values were calculated from the yield data over the five-year period, and the average yield was used to calculate the emission load. Out of the 25 monitored conventional farms, 25 of them cultivated wheat, 19 rye, and 14 oat; out of 25 monitored organic farms, 25 of them cultivated wheat, 17 rye, 16 oat and 12 spelt wheat.

The results show that there are considerable differences between conventional and organic farming systems in individual subcategories of the farm phase of the cereals production. The production of emissions in a farming cycle is divided into the basic groups: agrotechnical operations, fertilizers, pesticides, seeds, and field emissions, and the load in those basic groups differs depending on the cultivated crop and the selected farming system.

In organic farming, a higher emission load is produced within the scope of agrotechnical operations, which is due to a higher need of mechanical operations during vegetation and a lower production effectiveness, in particular. Within the framework of the group of agrotechnical operations, the evaluated operations included stubble plowing, plowing, application of synthetic fertilizers (several times during the agricultural cycle), application of farm fertilizers, preseeding preparation and sowing, application of growth regulators, harrowing, treatment against weeds, diseases and pests, treatment against lodging, and harvesting. The conversion to the production unit, i.e. quantification of the emission load e.g. per kg of grain, in combination with the lower yields of organic farming cause that in this basic group the GHG emissions are lower for conventionally grown cereals than for those grown in organic farming systems (Fig. 2). Where the conversion involves GHG emissions produced per area unit (ha), the differences between the farming systems are considerably lower for individual cereals; as for rye, the load from the basic category "agrotechnical operations" is higher for a conventional farming system (Fig. 6).

In organic farming, the emission load from agrotechnical operations amounts to 0.132 kg CO_{2e} / kg of grain for wheat, 0.113 kg CO_{2e} / kg of grain for rye, 0.116 kg CO_{2e} / kg of grain for oat and 0.120 kg CO_{2e} / kg of grain for spelt wheat, while in conventional farming, the emission load amounts to 0.078 kg CO_{2e} / kg of grain for wheat, 0.088 kg CO_{2e} / kg of grain for rye and 0.045 kg CO_{2e} / kg of grain for oat.

A number of authors, such as Berner et al. (2008), Dorninger and Freyer (2008), Chen et al. (2013), Lal (2004b), and Teasdale et al. (2007), state changes of agrotechnical procedures as one of the ways how to reduce GHG emissions. The proposed measures are minimization, omission of plowing, limitation of the number of crossings by merging operations, but also deep application of fertilizers, incorporation of plant residues or changes in irrigation for some crops.

Another important basic group is field emissions. This fact is also confirmed by Mori et al. (2005), Tokuda and Hayatsu (2004) and Zou et al. (2005) who claim that a growing use of chemical fertilizers and manure is usually accompanied by a growing share of N_2O released from the soil. Determination of field emissions is difficult because field emissions are very varied, depending on a large number of variables, such as soil properties, climatic conditions, land management methods, etc. (Brentrup et al., 2000; Brentrup, 2003). Differences between individual farming systems are apparent even in this group, and the differences after the conversion to a production unit are due to the different yields in individual farming systems as well as due to the different fertilization and subsequent soil processes. Fig. 3 clearly shows that in this basic group, GHG emissions are higher for wheat grown in an organic farming system (0.187 kg CO_{2e} / kg of grain) than for wheat grown in a conventional system (0.137 kg CO_{2e} / kg of grain). Contrarily, the field emissions from the growing of oat and rye in an organic farming system (0.123 kg CO_{2e} / kg of grain for oat, 0.116 kg CO_{2e} / kg of grain for rye) are lower than when grown in a conventional system (0.127 kg CO_{2e} / kg of grain for oat, 0.175 kg CO_{2e} / kg of grain for rye). As for spelt wheat grown in an organic farming system, this value amounts to 0.170 kg CO_{2e}/kg of grain.

Fertilization is regarded as the most significant basic group, which also accounts for the greatest difference in GHG emissions between conventional and organic farming systems, which is consistent also with the finding by Cambria et al. (2016). According to Fott et al. (2003), agricultural emissions are mostly released from the applied fertilizers and pesticides, which is also in line with the findings of Biswas et al. (2008). In organic farming, the main cause of the reduction of emissions in the basic group "fertilizers" is the elimination of synthetic fertilizers. The production and transport of such fertilizers consume a large amount of energy, thus creating a considerable environmental load (Cormack and Metcalfe, 2000; Williams et al., 2006).

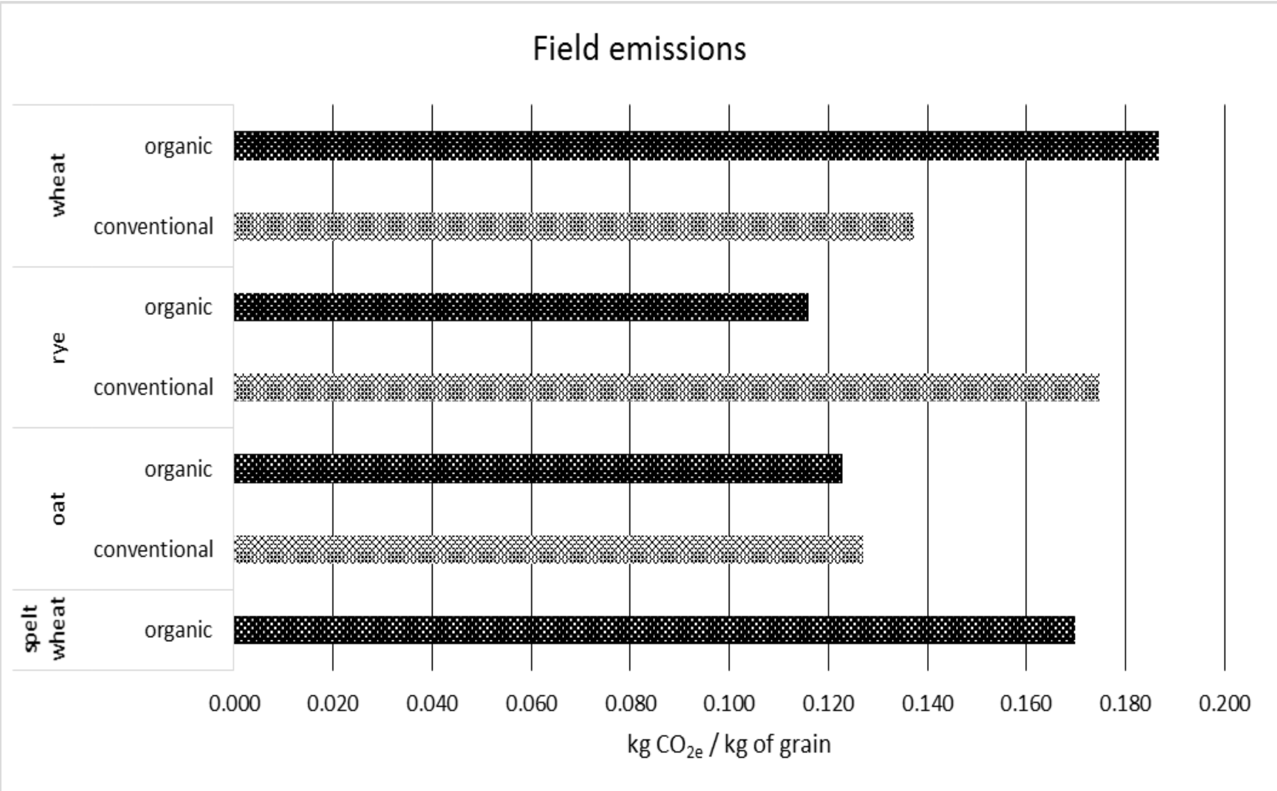

Fig. 3. GHG emissions from the basic category "field emissions"

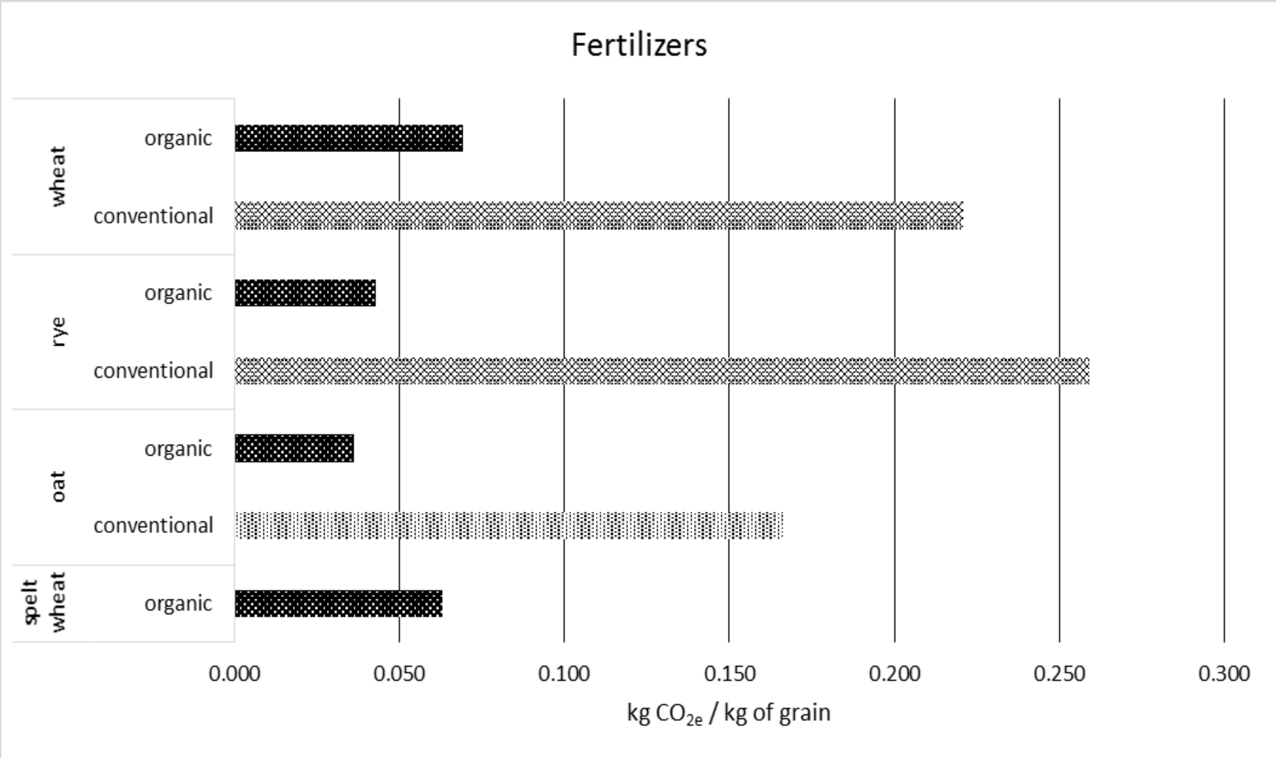

Fig. 4. GHG emissions in the basic category “fertilizers”

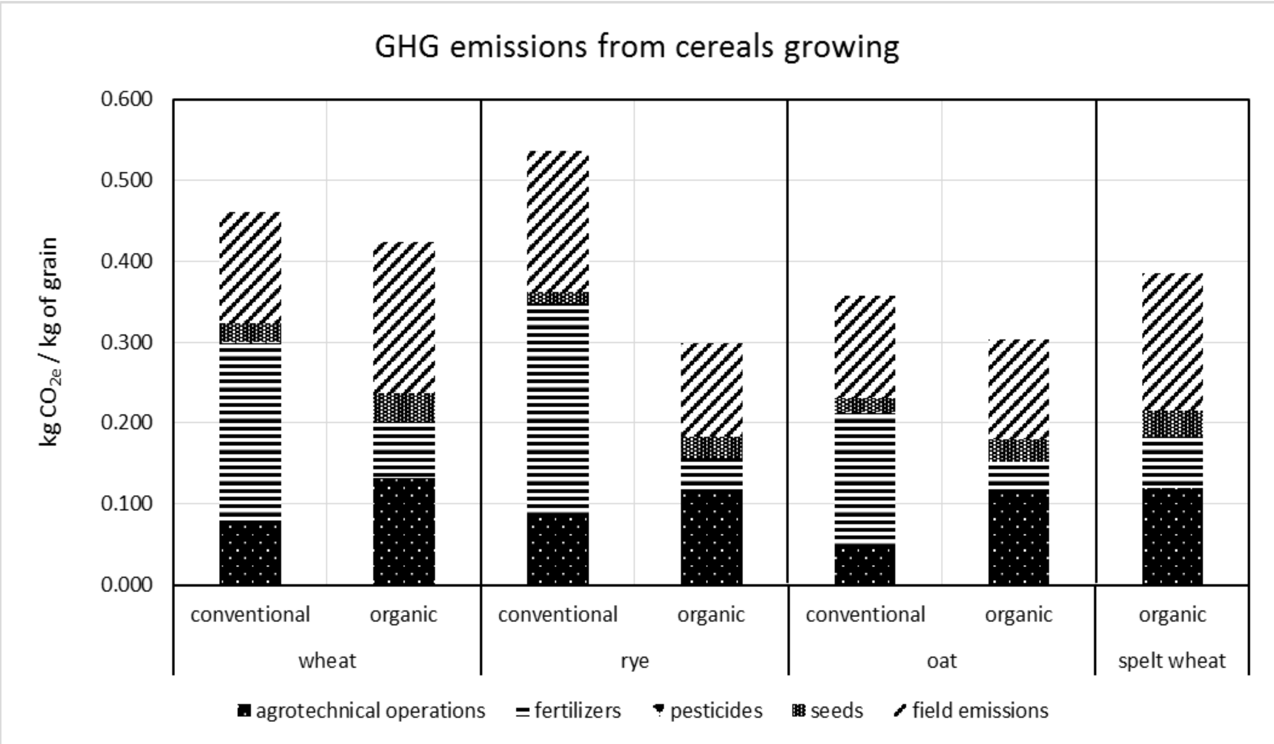

Fig. 5. GHG emissions from cereals growing – conversion to a production unit

Kindred et al. (2008) report that 11 kg CO_{2e} per kilogram of *N* are produced during the production, packing and transport of synthetic nitrogen fertilizers. In 2007, the total GHG emissions from the production and application of nitrogen fertilizers from fossil fuels amounted to 750-1080 million tons of CO_2 equivalent (1-2 % of the total global GHG emissions), while 47 years earlier, in 1960, it was less than 100 million tons of CO_{2e} (Niggli et al., 2011). Changes in fertilization, i.e. a certain degree of extensification and a correct use of organic fertilizers, may result in reduction of CO_{2e} emissions, which is in line with the statements of) Johnson et al. (2007) and Smith et al. (2008). The need for more precise nitrogen management in organic farming systems is also indicated by Kramer et al. (2006).

A considerably lower emission load generated by organic farming in the basic group "fertilizers" is evident for all the monitored cereals (Fig. 4). The highest load is produced in conventional farming as a result of application of synthetic nitrogen fertilizers. These values are 0.221 kg CO_{2e} / kg of grain for wheat, 0.259 kg CO_{2e} / kg of grain for rye, and 0.167 kg CO_{2e} / kg of grain for oat. In organic farming systems, these values are considerably lower – the emissions from fertilizers amount to 0.069 kg CO_{2e} / kg of grain for wheat, 0.043 kg CO_{2e} / kg for rye, 0.036 kg CO_{2e} / kg of grain for oat, and 0.063 kg CO_{2e} / kg of grain for spelt.

In terms of greenhouse gas emissions, the emissions from the basic group "seeds" appear to be less significant, and the emissions from the basic group "pesticides" seem to be almost negligible. As for seeds, the GHG emissions are always higher in organic farming systems due to lower yields (0.035 kg CO_{2e} / kg of grain for wheat, 0.026 kg CO_{2e} / kg of grain for rye, 0.027 kg CO_{2e} / kg of grain for oat, 0.032 kg CO_{2e} / kg of grain for spelt wheat) as compared to conventional farming systems (0.023 kg CO_{2e} / kg of grain for wheat, 0.014 kg CO_{2e} / kg of grain for rye, 0.018 kg CO_{2e} / kg of grain for oat), and the values are even considerably lower for pesticides. Pesticides are not applied in organic farming systems; in conventional systems, the emission load from pesticides is around 0.001 kg CO_{2e} / kg of grain for wheat and rye, and 0.002 kg CO_{2e} / kg of grain for oat. The environmental impact of the use of pesticides consists especially in their toxicity (De Backer et al., 2009).

As evident from Fig. 5, there are also significant differences between individual cereal species; when comparing particular species in various farming systems, the total emission load is always higher in conventional farming, even when converted to a production unit. These values amount to 0.460 kg CO_{2e} / kg of grain for wheat, 0.537 kg CO_{2e} / kg of grain for rye and 0.358 kg CO_{2e} / kg of grain for oat. In organic farming, these values amount to 0.423 kg CO_{2e} / kg of grain for wheat, 0.298 kg CO_{2e} / kg of grain for rye, 0.303 kg CO_{2e} / kg of grain for oat and 0.385 kg CO_{2e} / kg of grain for spelt wheat.

A disadvantage of organic farming is a lower production per area unit, which increases the emission load per production unit. For example, in Europe, the average yields of wheat in organic farming amount to 80 % of the conventional production (Lackner, 2008). Differences in yields in conventional and organic farming are also expressed by Mondelaers et al. (2009) who state that the average yields of organic farms are 17 % lower than those of conventional farms. On the other hand, Pimentel et al. (2005) claim that organic farming systems may achieve yields comparable with those of conventional systems for some high-production plants, such as maize. Increasing the yields in organic farming while maintaining its environmental friendliness may further increase its efficiency as a tool for reducing greenhouse gas emissions in agriculture.

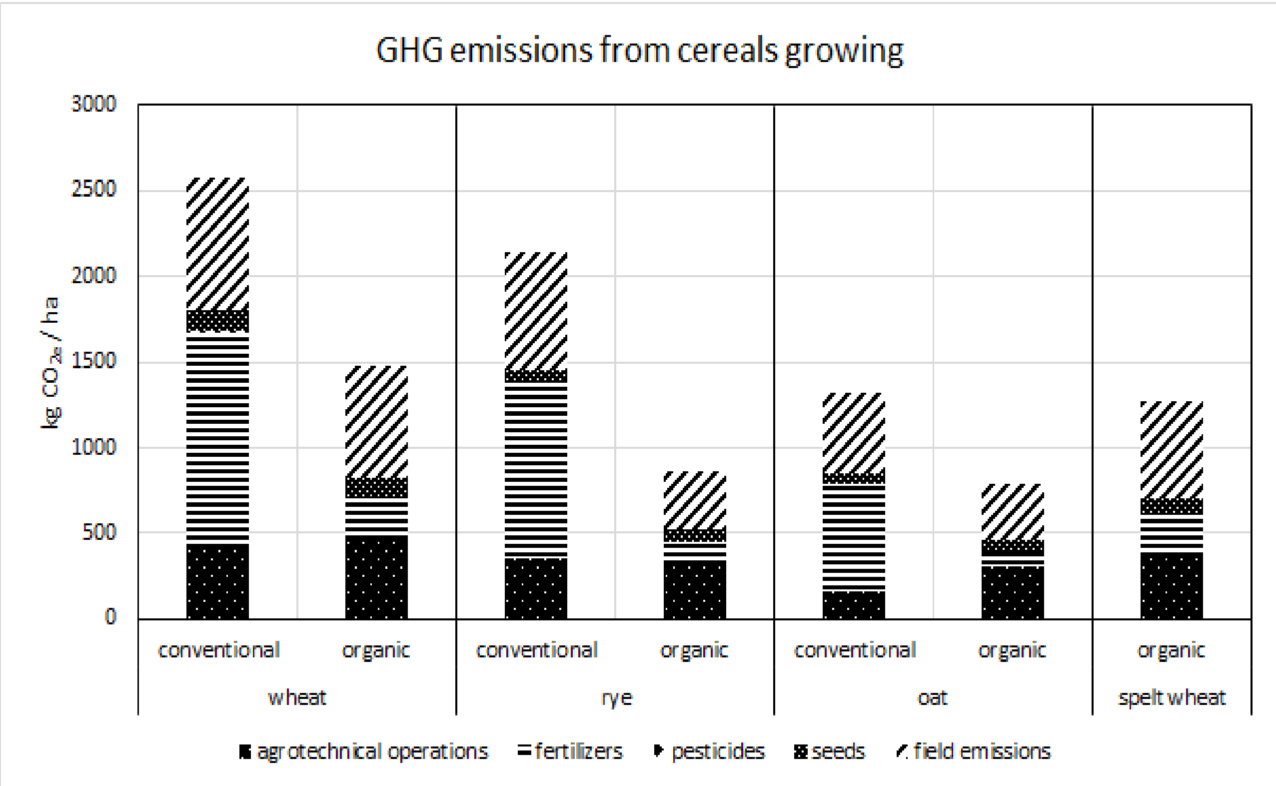

Fig. 6. GHG emissions from cereals growing – conversion to an area unit

Nemecek et al. (2005) argue that the environmental savings per area unit in organic farming are approximately double the savings calculated per production unit, which is due to the differences in yields. Knudsen (2010) also state that due to the lower yields in organic farming, the calculations of the production of greenhouse gas emissions per production unit show an increased environmental load in relation to conventional farming, so the resulting difference is lower than when converted to a unit of area.

This is in line with the findings of Mondelaers et al. (2009) who claim that due to the lower yields of organic farming, particularly in less developed countries, the environmental effect consisting in a reduction of greenhouse gas emissions is lower when converted to a production unit instead of an area unit, and in extreme cases it may even be negative. However, in both types of calculation the production of greenhouse gases remains lower in organic farming for many crops (Moudrý et al., 2013).

Considerable differences in GHG emissions after the conversion to an area unit are also well visible from Fig. 6. Given the average yields 5.6 t/ha for wheat, 3.7 t/ha for oat and 4.0 t/ha for rye, a conventional farming system produces 2577 kg CO_{2e} / ha for wheat, 2147 kg CO_{2e} / ha for rye and 1325 kg CO_{2e} / ha for oat. Similar figures (2330 kg CO_{2e} / ha for wheat, 2270 kg CO_{2e} / ha for rye and 1800 kg CO_{2e} / ha for oat) are also given by Rajaniemi et al. (2011). Given the average yields 3.5 t/ha for wheat, 2.6 t/ha for oat, 2.9 t/ha for rye and 3.3 t/ha for spelt wheat, an organic farming system produces 1482 kg CO_{2e} / ha for wheat, 865 kg CO_{2e} / ha for rye, 787 kg CO_{2e} / ha for oat and 1271 kg CO_{2e} / ha for spelt wheat.

So the evaluation of the emission load from the growing of cereals in conventional and organic farming systems in the conditions of Central Europe confirms the findings of Dorninger and Freyer (2008) who state that GHG emissions may be reduced by a correct choice of the farming system.

4. Conclusions

In crop production, a certain scope for reducing greenhouse gas emissions is also available in the growing of cereals, which are the most widely grown group of crops in many countries. The results show that the total emission load produced in organic farming systems is lower both when converted to an area unit and when converted to a production unit. Some savings may be achieved particularly by changes in the use of nitrogen fertilizers and partially by changes in agrotechnical measures.

In terms of agrotechnical operations, GHG emissions can be reduced in both conventional and organic farming, e.g. by omitting plowing and replacing it with shallow soil cultivation, another possibility is the use of tractors with lower performance and consumption, for example, during harrowing, or generally when working with lighter tools. Savings can also be achieved by lowering the number of crossings by performance of multiple agrotechnical operations at the same time.

Yields are a key factor in organic farming. Their increase can be achieved by intensification of organic farming, with higher yields being supported, for example, by precise selection of varieties in view of their suitability for specific habitat conditions, nutrient requirements and resistance to weeds, diseases and pests, and also by observing suitable sowing dates, optimal sowing and plant placement or more precise plant nutrition.

In conventional farming, as a further measure, it is recommended to restrict plant production without any link to animal husbandry, to extend sowing practices, in particular by incorporating leguminous plants, including perennial plants (alfalfa, clover), or by cultivating varieties for better use of nutrients. Reducing the need for synthetic fertilizers, especially nitrogen fertilizers, leads to a significant reduction of the emission load. Based on the results, it can be stated that a change in the farming system may help reduce the emission load in agriculture.

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