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Assessment of the greenhouse gas emissions and energy inputs applying different weed control methods for wheat growing

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Abstract. Economic indicators are often used to evaluate and select technologies, determining the production costs of the product. However, according to the EU's green course, the ecological assessment of technologies is increasingly important. The purpose of the article is to comparatively evaluate two winter wheat weed control methods, which are widely used in Latvia, according to two ecological indicators - the amount of the GHG emissions and the energy consumption, to find out whether these indicators can serve as a criterion for the selection of technologies. These two methods are HA (harrowing), in which weeds are controlled by harrowing and herbicides, HE (herbicides), in which weeds are controlled only by herbicides. The methodology for calculating the mentioned indicators was developed by analyzing several studies by other authors. The total GHG emissions generated are calculated as the sum of five components: emissions, generated for the manufacture and delivery of the machinery used; emissions, generated by the fuel, consumed for implementation of the technology; emissions, generated for the production, delivery and installation of fertilizers; emissions, generated for the production, delivery and installation of pesticides, seed production, delivery and installation emissions. Analogously, the total energy consumption is calculated by summing the components The technologies were implemented on a specific farm, with the machinery of this farm, labor, fertilizers and the plant protection products. It has been established that the technologies differ by the calculated ecological indicators within the range of 1.2–2.6%; moreover, these indicators are lower for the technology with the herbicide spraying, and the technology is simpler to implement. Therefore, it is also more widely used. Since the coefficients for the calculation of the ecological indicators can be applied by the methodology of this article, the characteristics of the technique and the doses of fertilizers and the plant protection agents, used on the farms, are known, the ecological indicators can be used as an additional criterion for the selection of technologies on the farms. The ratio of the energy value and energy consumption of the produced product (the output and the input ratio) was also determined, this indicator for technologies HA and HE being, respectively, 8.30 and 8.41. In comparison with the research by the authors in other countries, from the point of view of the amount of the generated CO_2-eq emissions and rational consumption of energy, the analysed winter wheat production technologies are evaluated as moderately efficient, but from the point of view of the energy value of the product produced and the ratio of the energy consumption (the output and the input ratio) - as efficient.

Key words: wheat growing, technologies, GHG emissions, energy input, energy output.

INTRODUCTION

The criteria, most often used for the selection of the agricultural crop production technologies, are economic ones; yet, in connection with the ‘green course’ (Beltrán, J.P et al., 2021) accepted by the EU, the importance of the ecological assessment of the product production technologies is increasing also in agriculture. Within the EU framework of Common agricultural policy (CAP) Strategic Plans for the Latvia is planning in agriculture for 2023–2027 to reduce the use of pesticides by 17.8% and the use of mineral fertilizers by 18.3% in agriculture. (Regulation (EU), 2021) one of the most important characteristics of the ecological impact is the amount of the GHG emissions per unit of the produced output (CO_2eq t^{-1}) or a unit of the cultivated area (CO_2eq ha^{-1}). The designation CO_2eq means that the emissions of not only CO_2, but also of other greenhouse gases - CH_4 and N_2O - is evaluated (EEA, 2001). In Latvia, too, options for reducing the GHG emissions have been studied in several studies. The most extensive of them is monograph (Rivza, 2018), which evaluates possibilities of reducing the GHG emissions in agriculture, animal husbandry and forestry, as well as their reduction costs for different types of farm clusters. An evaluation of the GHG emission capacity of the main agricultural products was made in study (Popluga, 2018). Changes in the soil organic carbon stock during the production of different types of agricultural products are shown in work (Lazdins, 2019). In Latvia the issue of changes in the amount of GHG emissions when producing agricultural products with different technologies has not been studied so far - this issue, together with the economic analysis and energy consumption (input) in the cultivation of the field beans, using different weed control technologies, is discussed in article (Rucins et al., 2022). There are publications on the research in the Scandinavian and Baltic countries (Conijn et al., 2014; Elsgaard, 2015; Kazlauskas et al., 2021). They consider the suitability of crops for the production of biofuels from the point of view of the GHG emissions and develop a tool for the calculation of the GHG emissions when obtaining bioenergy from agricultural products, examine the impact of various fertilization methods upon the amount of the GHG emissions. These issues have been widely studied in the USA, for example (West & Marland, 2002); there has been considered the impact of various types of tillage upon the amount of emissions; in (Camargo et al., 2012) an analysis tool has been developed to evaluate the energy production and GHG emissions for various farming systems. However, in Latvia, only the principles of the US and Canadian studies can be used, as our research conditions are different.

The aim of the work is to evaluate two commonly used winter wheat production technologies with different types of the weed control techniques according to the generated GHG emissions and energy consumption, thus checking the methodology and creating an opportunity in the future to optimize agricultural crop production.

MATERIALS AND METHODS

The field plant technologies are characterized by the data about the equipment used, labour and fuel consumption, the used amounts of seeds, fertilizers and herbicides, and about the amount of the product obtained (Rucins et al., 2022). In this research the generated GHG emissions and energy consumption are calculated only from the technical factors; emissions from the soil, plants and other biological factors are not studied. Further development of this research aims to develop a simple tool for estimating emissions, related to technical factors.

Two winter wheat cultivation technologies (HA, HE) have been implemented in a peasant farm (56°26'44.3"N 22°44'37.5"E) with an area of 40 ha. For both technologies the same methods of tillage, sowing and fertilizing are used: in autumn - direct sowing in the stubble after harvesting the field beans and one-time herbicide spraying, in spring - fertilization with mineral fertilizers containing the same amount of K and N, with multiple spraying of an equal amount of fungicides and trace elements. The technologies differ with the weed control methods: HA - the crops are harrowed at the beginning of April, HE - they are treated with an herbicide at the beginning of May. The machines, used in similar operations and its efficiency, are the same for both technologies; however, the total amount of pesticides is higher in the second scheme, the amount of the fuel consumed is different for each scheme. The technologies are shown schematically in Table 1, the calendar terms of the works are also shown there, as well as the labour and fuel consumption for the implementation of the operations. During the study it was not possible to change the amounts of fertilization and herbicides, used at the farm.

Table 1. Scheme of the winter wheat cultivation technologies HA, HE (pre - plant - field beans), yield 8 t ha^{-1}

Date	Operation	Productivity, ($ha\ h^{-1}$)	Fuel consumption, ($L\ ha^{-1}$)	Load, ($ha\ year^{-1}$)	Technology
2020					
10.09.	Direct sowing, row spacing 30 cm, (250 kg ha^{-1})	4.0	10.0	600	HA, HE
23.09.	Herbicide spraying (0.5 L ha^{-1} Komplet)	25.2	2.0	3,780	HA, HE
23.09.	Water supply	22.0	2.0	3,780	HA, HE
2021					
26.03.	Fertilization (270 kg ha^{-1} N30+S7)	36.0	3.0	4,500	HA, HE
09.04.	Fertilization (93 kg ha^{-1} KCL)	36.0	3.0	4,500	HA, HE
09.04.	Harrowing	4.8	3.0	345	HA
17.04.	Mix spraying (1 L ha^{-1} Input, 1.4 L ha^{-1} Cyclocel, 1.5 L ha^{-1} Profi Basis Plus)	25.2	2.0	3,780	HA, HE
17.04.	Water supply	22.0	2.0	3,780	HA, HE
27.04.	Fertilization (300 kg ha^{-1} N30+S7)	36.0	3.0	4,500	HA, HE
13.05.	Mix spraying (0.4 L ha^{-1} Moduss, 1.5 L ha^{-1} Profi Basis Plus)	25.2	2.0	3,780	HA
13.05.	Mix spraying (0.4 L ha^{-1} Moduss, 1.5 L ha^{-1} Profi Basis Plus, herbicide (0.5 L ha^{-1} Zypar, 0.02 kg ha^{-1} TBM)	25.2	2.0	3,780	HE
13.05.	Water supply	22.0	2.0	3,780	HA, HE
07.06.	Fertilization (97 kg ha^{-1} N30+S7)	36.0	3.0	4,500	HA, HE
09.06.	Fungicide spraying (Ascra xpro 1.5 L ha^{-1})	25.2	2.0	3,780	HA, HE
09.06.	Water supply	22.0	2.0	3,780	HA, HE
30.08.	Harvesting	2.5	30.0	1,500	HA, HE
30.08.	Grain transport	2.3	8.0	1,500	HA, HE

As evident in the table, technology HA has one weed control operation - harrowing - more than HE, while additional herbicide spraying in HE is combined with fungicide and trace element spraying (13.05.2021).

The methodology for evaluation of the GHG emissions resulting from the use of the different technologies, is based on separate calculations of the emission components with subsequent summation. Several authors (Audsley et al., 2009; Li et al., 2019) recommend that the total emissions calculated as the sum C (Eq. 1) of five components: emissions C_1 (Eq. 2), created by the equipment for the implementation of technological operations and its delivery; emissions C_2 (Eq. 3), created by the fuel, consumed for the implementation of the technology for the fertilizer production, supply and processing; emissions C_3(Eq. 4) for the pesticide production, supply and processing; emissions C_4 (Eq. 5) for the seed production, supply and processing C_5 (Eq. 6).

$$C = C_1 + C_2 + C_3 + C_4 + C_5 \quad (1)$$

$$C_1 = \left(\frac{m_t}{L_{\Sigma t}} k_t + \frac{m_m}{L_{\Sigma m}} k_m\right) * F \quad (2)$$

where m_t – the mass (weight) of the tractor, kg; m_m – the mass (weight) of the machine, kg; $L_{\sum}t$ – the total number of working years per tractor, years; $L_{\sum}m$ – the total number of working years per machine, ~~h~~ years; k_t – the factor of the overall emissions of the tractor, kg CO_2eq kg^{-1}; k_m – the factor of the overall emissions of the machine, kg CO_2eq kg^{-1}; F – the load per year per machine or tractor, ha years^{-1}.

$$\mathrm{C_2 = S_f * k_f} \quad (3)$$

where S_f – the fuel consumption, L ha^{-1}; k_f – the emission factors of fuels, CO_2eq, kg L^{-1}.

$$C_3 = \sum S_{fert1} * k_{fert\,1} + \sum S_{fert2} * k_{fert\,2} \quad (4)$$

where Sfert1 – rate of fertilizers 1, kg ha^{-1}; Sfert2 – rate of fertilizers 2, kg ha^{-1}; kfert1 – emission factors of fertilizers 1, CO2eq kg N^{-1}; kfert2 – emission factors of fertilizers 2, CO2eq kgK2O^{-1}.

$$C_4 = \sum S_{pest4} * k_{pest4} \quad (5)$$

where S_{pest4} – the rate of pesticides, kg ha^{-1}; k_{pest1} – the emission factors of pesticides, CO_2eq kg^{-1}.

$$C_5 = S_s * k_s \quad (6)$$

where S_s – rate of seeds, kg ha^{-1}; k_s – emission factors of seeds, CO_2eq kg^{-1}.

Using the calculation of the GHG emissions as an ecological evaluation of technologies, several authors (Tzilivakis et al., 2005; Li et al., 2019; Bruciene et al., 2021) make use of the energy input. This indicator describes how much energy (MJ) must be invested to grow a ton of production (MJ t^{-1}), or what the energy consumption is for the implementation of the technology per area unit (MJ ha^{-1}). The calculated indicator can be compared with the amount of energy obtained from the harvested product (the energy output) MJ ha^{-1}, thus evaluating the suitability of different crops for the energy production or the economic profitability of production (CIGR Handbook, 1999; Woods et al., 2005). In several studies (Kallivroussis et al., 2002¸ Kolarikova et al., 2014) it is recommended to calculate the consumption of energy E (Eq. 7) as the sum of human labour energy E_1 (Eq. 8), consumed for the implementation of the technology; energy E_2 (Eq. 9), consumed for the manufacture and delivery of the used equipment; energy E_3 (Eq. 10) consumed for the production and delivery fuel; energy E_4 (Eq.11), consumed for the production and delivery of fertilizers; energy E_5 (Eq. 12), consumed for the production and delivery of pesticides; and energy E_6 (Eq. 13), consumed for the production and delivery of seeds.

$$E = E_1 + E_2 + E_3 + E_4 + E_5 + E_6 \quad (7)$$

$$E_1 = S_{hl} * e_{hl} \quad (8)$$

where S_{hl} – the consumed human labour per hectare, h ha^{-1}; e_{hl} – energy equivalent to the human labour, MJ h^{-1}.

$$E_2 = \frac{m * e_e}{T_\Sigma * W} \quad (9)$$

where m – the mass (weight) of the machine or tractor, kg; e_e – the conversion equivalent, MJ g^{-1}; T_Σ – the working time per machine or tractor, h; W – the productivity of the machine, ha h^{-1}.

$$E_3 = S_f * e_f \quad (10)$$

where S_f – the fuel consumption, L ha^{-1}; e_f – the energy equivalent of fuels, MJ l^{-1}.

$$E_4 = S_{fert1} * e_{fert1} + S_{fert2} * e_{fert2} \quad (11)$$

where S_{fert1} – the rate of fertilizers 1, kg ha^{-1}; S_{fert2} – the rate of fertilizers 2, kg ha^{-1}; e_{fert1} – the energy equivalent of fertilizers 1, MJ kg_N^{-1}; e_{fert2} – the energy equivalent of fertilizers 2, MJ kg_{K2O}^{-1}.

$$E_5 = \sum S_{pest} * e_{pest} \quad (12)$$

where S_{pest} – the rate of pesticides, kg ha^{-1}; e_{pest} – the energy equivalent of pesticides, MJ kg^{-1}.

$$E_6 = S_s * e_s \quad (13)$$

where S_s – the rate of seeds, kg ha^{-1}; e_s – the energy equivalent of seeds, MJ kg^{-1}.

Coefficients *k* and *e*, found in the literature sources and used in the calculations, are summarized in table (Table 2). Various authors indicate different values of these coefficients; for the calculations there were chosen the most appropriate ones for the described technologies and production conditions.

Table 2. Coefficient's *k* and *e* for the calculation of the GHG emissions (CO_2eq) and energy input (MJ) in technologies HA; HE

Item	Emission factors		Source	Energy equivalents			Source
	Abbr.	(kg CO_2 eq kg^{-1})		Abbr.	Value	Units	
Human labour				e_{hl}	2.3	MJ ha^{-1}	CIGR Handbook, 1999
Tractor	k_t	14.41	Li et al., 2019	e_e	142.7	MJ kg^{-1}	Li et al., 2019
Machine	k_m	10.23	Li et al., 2019				
Fuel	k_f	3.36	Elsgaard, 2015	e_f	56.31	MJ l^{-1}	Gundogmus & Bayramoglu, 2006
Fertilizer 1	k_{fert1}	4.57	Audsley et al., 2009	e_{fert1}	74.20	MJ kg^{-1}	Kallivroussis et al., 2002
Fertilizer 2	k_{fert2}	0.68	Jenssen & Kongshaug, 2003	e_{fert2}	14.30	MJ kg^{-1}	Kallivroussis et al., 2002
Pesticides	k_{pest}	7.90	Audsley et al., 2009	e_{pest}	5.71	MJ kg^{-1}	Bruciene et al., 2021
Seeds	k_s	0.87	Woods et al., 2005	e_s	7.00	MJ kg^{-1}	Lal et al., 2019

All the technological operations were performed with the equipment of the farm; its characteristics and data for calculations are given in table (Table 3), the data on the labour, productivity, load and fuel consumption for the implementation of technologies HA and HE are in table (Table 1).

The GHG and energy input summarized results of the calculations, on their turn, are presented according to equations (2) – (6) and (8) – (13) in table (Table 4).

In order to determine the total GHG emissions for technologies HA and HE, first, using equations (2) – (6) and the data, given in tables (Tables 1, 2, 3), there are calculated the emission components $C_1 – C_5$ of each operation. If materials (fuel, fertilizer, chemicals, seeds) are used during the operation, the emissions, created for their production and delivery, are added to the emissions of the relevant operation. If the operation is performed several times, the result is multiplied by the number of times. The most complicated is the calculation of the component C_1 of emissions, created for the manufacture and delivery of the equipment (tractor + machine) because the formula includes 7 parameters. By summing the emissions, created by all operations, the total emissions *C* of each technology are obtained. Similarly, using equations (8) – (13) and the data of Tables 1, 2, 3, the energy consumption of each operation (energy input) and the total energy consumption of each technology *E* is obtained.

Table 3. Data for calculation of GHG emissions (CO_2eq) and energy input (MJ) in technologies HA; HE

Working operation (number of operations)	Tractor	Machinery (working width, m)	Weight, kg		Working time	
			m_t	m_m	$T_\sum$ hours	$L_\sum t$ years
Direct sowing	JD8335	Horsch Focus, (6)	13,000	9,500	1,500	10
Spraying (x4)	JD8335	Amazone, (36)	13,000	8,665	1,500	10
Water supply (x4)	JD6900	Cask, 14 t	5,390	4,000	1,500	10
Fertilization (x5)	JD6830	Rauch Accent, (36)	5,880	4,600	1,500	10
Harrowing	JD6830	Einboeck, (6)	5,880	620	720	10
Harvesting	-	JDS685i (9)	-	18,700	9.00	15
Grain transport	JD6920	Umega, 14t	8,400	4,450	1,500	10

m_t – the mass (weight) of the tractor, kg; m_m – the mass (weight) of the machine; $T_\sum$ – the working time per machine or tractor, h; $L_\sum t$ – the total number of working years per tractor, years.

RESULTS AND DISCUSSION

The differences in the amount of the GHG emissions and the energy consumption between the technologies HA and HE are small - 1.2–2.6% (Table 4). This can be explained by the fact that the technologies differ only by one operation - harrowing HA, and a dose of herbicides is added to one spray of the trace elements HE; besides a technology (HE) with an herbicide spray is simpler to implement. In addition, the results are also impacted by the calculation methodology used and the coefficients *k* and *e* chosen to calculate GHG emissions and energy input. The costs according to the methodology (Rucins et al., 2022) are 16.1 € h^{-1} for cultivation and 28.6 € h^{-1} for spraying, including herbicides. Since in this case from an ecological point of view there is no significant difference between the chemical and the mechanical weed control, the result of the weed reduction can be important in the choice of a technology. This issue is partially discussed in Rucins et al. (2022) but the authors do not arrive at convincing results, finding that additional research is needed.

Table 4. Calculation of the GHG emissions *C* and the energy input *E* by operation of technologies HA and HE

Working operation	HA		HE	
(number of operations)	*C*, kg CO_2 eq h^{-1}	*E*, MJ h^{-1}	*C*, kg CO_2 eq h^{-1}	*E*, MJ h^{-1}
Direct sowing	288	2,562	288	2,562
Spraying (x4)	117	1,488	118	1,500
Water supply (x4)	41	538	41	538
Fertilization (x5)	747	8,057	747	8,057
Harrowing	**37**	**206**	**-**	**-**
Harvesting	113	1,927	113	1,927
Grain transport	73	652	73	652
Total	**1,416**	**15,430**	**1,380**	**15,236**

C – total emissions of HA and HE technologies; E – total energy input of the technologies HA and HE.

As one can see in Fig. 1, the total of 46–49% of the GHG emissions and the energy consumption in both technologies is constituted by fertilizers, the next largest component is fuel - 19% of the GHG emissions and 29% of the energy consumption, 15% and 11% are seeds, about 13% and 7% is the technical part, and 4–6% - the pesticide part.

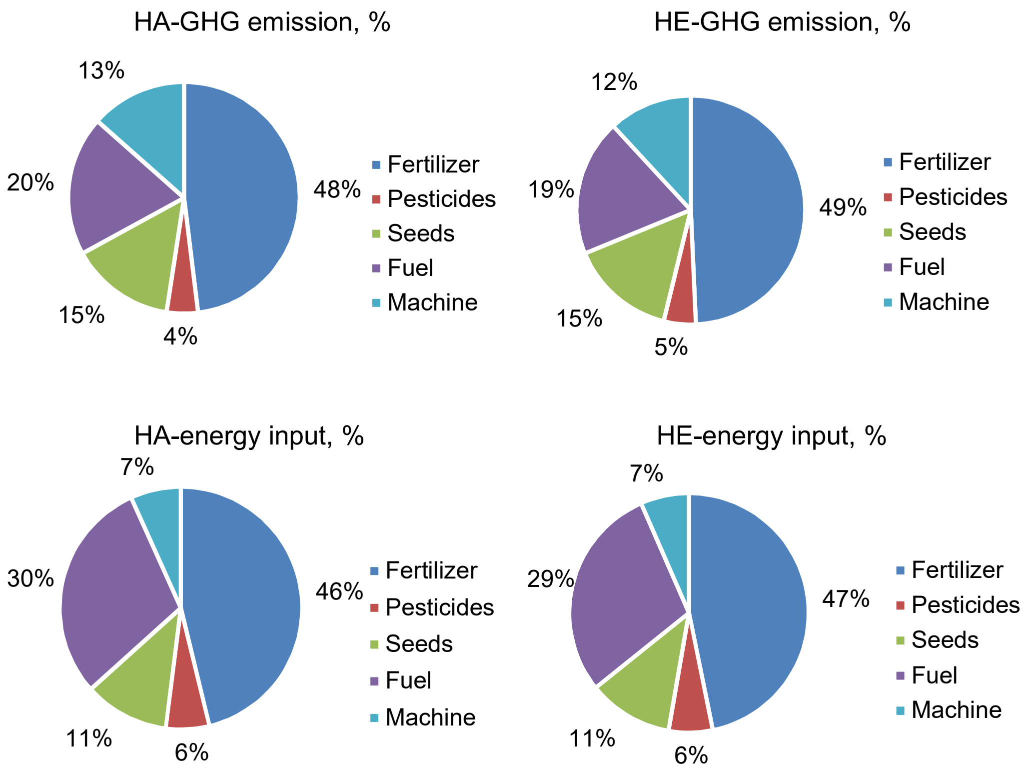

Figure 1. The GHG emissions and the energy input in technologies HA and HE, calculated by components from Table 4.

A similar distribution of components - 46–45% fertilizer, 25–30% fuel with regard to GHG emissions and energy consumption was found by the authors of studies Kallivroussis et al. (2002) and Wang et al. (2015).

A compilation of studies by various authors on the amount of the GHG emissions in wheat cultivation in eight different countries can be found in Appendix 1 of article (Popluga, 2018), where the results are indicated as 750–2,396 kg CO_2eq ha^{-1}. It has been emphasized in the article that the amount of emissions may vary significantly depending on the production technology, the management system, the climatic conditions, and the indicators characterizing the soil. On the other hand, in (Elsgaard et al., 2013) there are mentioned emissions of 1,939–2,003 kg CO_2 eq ha^{-1} in wheat cultivation in Denmark; in source (Kazlauskas et al., 2021) - emissions 1,242.9 kg CO_2 eq ha^{-1} in Lithuania. The results of calculation of the GHG emissions, shown in table (Table 2), are comparable to other studies, so they can be considered reliable, and they describe the reviewed technologies as moderately efficient when evaluating the amount of the CO_2 eq emissions.

The energy consumption in wheat cultivation has been studied in the USA (Amenumey & Capel, 2014), finding a consumption of 13,679 MJ ha^{-1}, and in Canada (Bandekar et al., 2022), where a consumption of 8,060–9,300 MJ ha^{-1} has been calculated (Fig. 3). In Lithuania, in its turn, the energy consumption in sugar beet cultivation has been found to be 27,844 MJ ha^{-1} (Bruciene et al., 2021). Our calculated consumption is higher than it is typical for large-scale production in the USA and Canada, and lower than calculated for the energy-intensive culture of sugar beet in Lithuania. The study (Mousavi-Avval et al., 2018) confirms the validity of the energy consumption calculation.

Comparison of calculated GHG emissions and energy consumption (input) with the indicators of other countries is shown in Fig. 2.

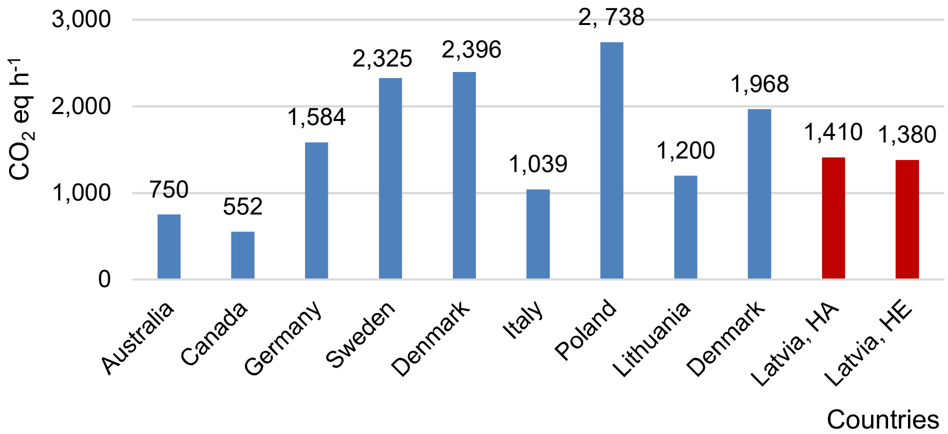

Figure 2. Comparison of GHG emissions with the indicators of other countries (Popluga, 2018)

On the whole, compared to the research by the authors from other countries, the analysed technologies may be evaluated as moderately efficient in terms of the amount of the GHG emissions and the energy consumption.

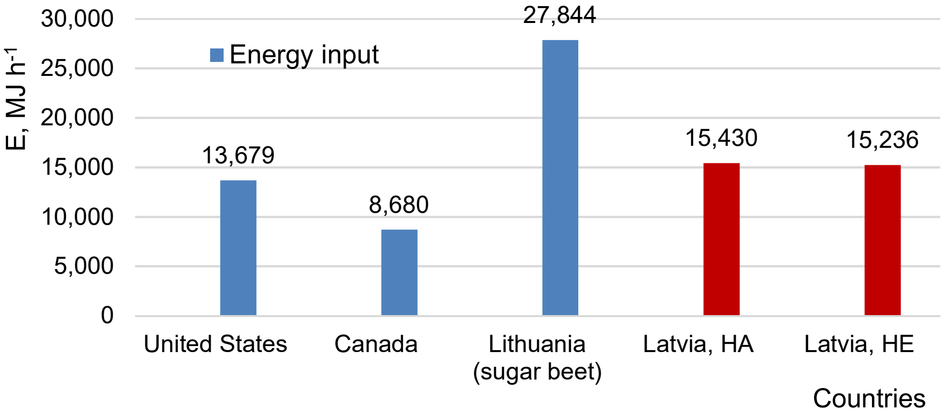

Figure 3. Comparison of energy input with the indicators of other countries (Amenumey & Capel, 2014; Bandekar et al., 2022; Bruciene et al., 2021).

Several studies by others authors (Tzilivakis et al., 2005; Ozturk, 2014; Zahedi et al., 2015; Bruciene et al., 2021) believe that the production efficiency can be evaluated by the ratio of the energy value of the produced product (wheat grain and straw) and the energy consumption (the output and input ratio). The energy value (output) is calculated by multiplying the yield per hectare in kg by the energy value factor. These coefficients in the analyzed values of the mentioned sources are assumed to be 14.7 MJ kg^{-1} for grain, 2.2 MJ kg^{-1} for straw. Considering the grain yield of 8 t ha^{-1}, the grain - straw ratio 1: 0.6, and the coefficients, indicated in Table 1, the energy value (output) for both technologies is 117,600 MJ h^{-1}, while the energy value of the produced product and the energy consumption ratio (output input ratio) for technology HA is 8.30, for technology HE 8.41. The mentioned authors indicate coefficients 4.50–9.70, our calculated values are in the upper band of the range, as three of the four authors indicate a lower yield of 5.5– 6.8 t h^{-1}. The reviewed technologies may be characterized as useful from the point of view of rational use of energy, which is indirectly confirmed by the fact that wheat is the most cultivated crop in the country.

CONCLUSIONS

Among the technologies, analysed in this study, no essential differences were found in terms of the amount of $CO_{2\ eq}$ emissions and energy consumption, which is probably why in practice, in most cases, the simplest technology is preferred - with additional herbicide spraying.

Since the CO_2 eq emissions and the energy consumption indicators are similar to the technologies, the results of the weed control would be important, requiring additional research.

The winter wheat production technologies, analyzed and widely used in Latvia, may be evaluated as moderately efficient from the point of view of the amount of the CO_2 eq emissions, created and the energy consumption, but as efficient from the point of view of rational use of energy, compared to the studies of authors from other countries.

The used methodology for determining the amount of the CO_2 eq emissions and energy consumption, using the coefficients given in the article for the calculation of ecological indicators, may be an additional criterion for choosing technologies and by developing it further, it is possible to create a tool for evaluation of emissions, related to technical factors on the farm.

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