ASSESSMENT OF ECONOMIC INDICATORS, ENERGY INPUTS AND GREENHOUSE GAS EMISSIONS APPLYING DIFFERENT WEED CONTROL TECHNOLOGIES FOR FIELD BEAN (*VICIA FABA* L.) GROWING: A CASE STUDY

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Abstract. A number of methods have been developed and are widely applied to evaluate the production of agricultural crops. These methods generally allow the assessment of technology only from an economic point of view, calculating costs of EUR·ha-1 or EUR·t^{-1}. To implement the EU green course, there is a need to minimize pesticide use, therefore it is important to evaluate the environmental impact of different methods of pest control. One of the best-known alternatives to herbicides is mechanical weed control. Harrowing and inter-row cultivation were tested during two years in the project. The efficacy of mechanical weed control was good and there was no yield loss when mechanical weed control was combined with a catch crop in field beans, compared to the usual weed control practice where herbicides are used to control weeds in spring. However, there is a concern about additional CO_2 emissions created by the mechanical weed control process. It is necessary to evaluate these additional emissions in the context of total CO_2 emissions created during the crop production cycle. In this study we take into account (1) the CO_2 emissions during the weed control process (2) and the CO_2 emissions created during the production, transport, storage and use of machinery, application of fertilisers and plant protection chemicals, burned fuel, and the sowing process. The study evaluated three technologies of weed control in field bean, T1, T2 and T3, with different soil tillage and weed control methods. The most significant difference was between the T2 and T3 technologies. In T2, mechanical weed control, harrowing and interrow cultivation, were used, while in T3 herbicides were used. The amount of fertiliser and most technological operations were the same for all technologies. The results show that for the technology T3 the equated costs are approximately by 9%-11% EUR·ha-1 lower than for technologies T1, T2 with mechanical weed control. The energy investment gap between technologies is small, 5%, while the CO_2 equivalent for emission in technology T3 is by 14% lower than in T2 and by 11% lower than in T2. Consequently, the most economically favourable technology is T3 that uses herbicides for weed control. This technology is also the most widely used on the farms. From the point of view of CO_2 emissions, fuel, sowing and engineering factors play a major role in the calculation of energy investment and CO_2 equivalent emissions, while the herbicide use and fertiliser factors are less important, however, the environmental impact of pesticides is often not taken into account.

Keywords: field bean, energy input, GHG emissions, weed control.

Introduction

The EU green course involves reducing pesticide use, therefore it is important to evaluate both the efficiency and the environmental impact of different methods of pest control. One of the best-known alternatives to herbicides is mechanical weed control. To compare economic efficiency and CO_2 emissions between technologies using chemical and mechanical weed control methods, a study of field bean (*Vicia faba* L.) crop production using different weed control methods was conducted in Latvia during two vegetation seasons, 2020 and 2021. The results of field trials are used to evaluate economic and environmental aspects of crop production technologies.

Usually farmers use the economic indicators, production costs EUR·t^{-1} or EUR·ha^{-1} as criteria for selection of a specific technological solution for crop production. The method of gross coverage recommended by the Latvian Rural Consultation and Education Centre [1] is widely used to calculate these indicators. The Latvia University of Life Sciences and Technologies developed a method of analysis of the technologies for the production of agricultural crops [2], which allows the simulation of production costs, depending on the main determinants, the number of techniques used, the number of fertilizer applications and the number of chemicals applied. A number of articles on the rational selection of machinery and technologies have been prepared and published using this method [3; 4]. The economic assessment of the technological solutions for the production of field beans was carried out using the proposed models [2; 4]. During the next planning period 2023-2029 the EU cohesion policy legislative framework will enable investments in a smarter, greener, more connected and more social Europe that is closer to its citizens, therefore the role of the environmental assessment of technologies is also very important. Many authors [e.g., 5-7] use the energy consumption (input) MJ·ha^{-1} and the GHG emissions CO_2eq·ha^{-1} generated to describe this effect. The results of the calculation of these indicators for each technology used are reported in this article. Both indicators include the energy consumption of machines, fertilizers, fuel, pesticides, seed production and use $MJ \cdot ha^{-1}$ and emissions $CO_2eq \cdot ha^{-1}$.

The aim of the work is to assess three field bean production technologies T1, T2, T3 with a variety of weed control techniques based on economic performance ($EUR \cdot ha^{-1}$), energy consumption $MJ \cdot ha^{-1}$ and GHG emissions $CO_2eq \cdot ha^{-1}$. The results of this study will help make a more comprehensive analysis of different production technologies.

Materials and methods

A study of field bean crop production in Latvia using different weed control methods was conducted in the project "Use of the latest technologies for weed control in arable crops in the integrated cultivation system"19-00-A01620-000078. During two vegetation seasons field beans were grown applying three different methods: stubble cultivation in spring (working depth – 18 cm, Kockerling Vector 800), harrowing and interrow cultivation (T1); mouldboard ploughing in the autumn (working depth – 18 cm, Kverneland PG-100-8), interrow cultivation in spring, harrowing and cultivation (T2); mouldboard ploughing in the autumn, cultivation in spring, three herbicide applications (T3).

Three different technologies (T1, T2, T3) were applied in the farm Vilciņi 1 in the Zemgale region, Latvia. Each treatment consisted of an experimental plot of 1ha (330x310 m), calculations were made accepting that 80 ha of field beans will be grown in total at farm level. Field bean growing technologies used in the study are summarized in Table 1.

Autumn sowing of the catch crop that was incorporated in the soil later in the autumn or in spring was the first operation in each of the technologies. In the first technology (T1) the only tillage operation was disc stubble cultivation in spring, mechanical weed control (harrowing, interrow cultivation) was implemented without the use of herbicides. In the second technology (T2) mouldboard ploughing was performed in the autumn and cultivation in spring. All other operations were the same in T1 and T2, insecticides and fungicides were sprayed five times. The third technology (T3) was similar to T2, but herbicides (sprayed three times) were used for weed control, altogether spraying was performed seven times. The amount of fertilizer and machinery used for the similar farming operations were the same in all three technologies. The total amount of pesticides was higher in T3. The amount of fuel used for the operations was different in each technology. The field beans 'Fuego' were sown on April 12 2021, at a sowing rate of 420 $kg \cdot ha^{-1}$ (55 plants m^{-2}), a seed sowing depth of 5 cm, a row spacing distance of 30 cm (sowing machine "Horsch Focus").

Table 1

Field bean (*Vicia faba* L.) growing technologies (previous crop – winter wheat)

Date	Operation	Technology
22.08.2020.	Catch crop – mixture of oats, peas 150 $kg \cdot ha^{-1}$	T1, T2, T3
06.11.2020.	Ploughing	T2, T3
09.04.2021.	Disc stubble cultivation	T1
09.04.2021.	Cultivation	T2, T3
09.04.2021.	Fertilizing, KCl (MOP) 110 $kg \cdot ha^{-1}$	T1, T2, T3
09.04.2021.	Fertilizing, Amofoss (MAP)130 $kg \cdot ha^{-1}$	T1, T2, T3
12.04.2021.	Sowing 420 $kg \cdot ha^{-1}$, row spacing 30 cm (55 plants per m^2)	T1, T2, T3
17.04.2021.	Herbicide spraying, (3.0 $l \cdot ha^{-1}$ Fenix)	T3
17.04.2021.	Water supply	T3
28.04.2021.	Harrowing	T1, T2
12.05.2021.	Harrowing	T1, T2
21.05.2021.	Herbicide spraying, (1.5 $l \cdot ha^{-1}$ Basagran)	T3
21.05.2021.	Water supply	T3
31.05.2021.	Mix spraying, (0.3 $l \cdot ha^{-1}$ Fastac, 2.0 $l \cdot ha^{-1}$; Moliboro)	T1, T2, T3
31.05.2021.	Mix spraying, (0.9 $l \cdot ha^{-1}$ Targa S; 0.3 $l \cdot ha^{-1}$ Fastac; 2.0 $l \cdot ha^{-1}$ Moliboro)	T3
31.05.2021.	Water supply	T1, T2, T3
21.05.2021.	Interrow cultivation	T1, T2
04.06.2021.	Interrow cultivation	T1, T2

Table 1 (continued)

Date	Operation	Technology
10.06.2021.	Mix spraying, (2.0 l·ha^{-1} ZOOM, 1.0 l·ha^{-1} Propulse, 0.2 l·ha^{-1} Evure)	T1, T2, T3
10.06.2021.	Water supply	T1, T2, T3
13.06.2021.	Insecticide spraying, (0.15 l·ha^{-1} Decis Mega)	T1, T2, T3
13.06.2021.	Water supply	T1, T2, T3
18.06.2021.	Insecticide spraying, (0.3 l·ha^{-1} Fastac)	T1, T2, T3
18.06.2021.	Water supply	T1, T2, T3
30.06.2021.	Mix spraying, (0.8 kg·ha^{-1} Signum, 0.15 l·ha^{-1} Decis Mega)	T1, T2, T3
30.06.2021.	Water supply	T1, T2, T3
30.08.2021.	Harvesting	T1, T2, T3
30.08.2021.	Grain transport	T1, T2, T3

Economical assessment

All technological operations were performed with the machinery available on the farm, the list of machinery used during the seasons 2020 and 2021, including weight, load, unit productivity, fuel and labour consumption of each machine, is given in Table 2. Machinery operational costs were calculated using the methodology described in the paper [1] with the computer program Excel. The costs of bean production for the T1, T2, T3 technologies in EUR·ha^{-1} were calculated by summing the operational costs with the costs of seeds, fertilizers and pesticides. Comparing the estimated costs of each technology allows to compare the economic benefits of the technologies.

Table 2

Input data for calculation of costs of field bean growing technologies T1; T2; T3

Operation (number of operations)	Price, EUR		Annual load, h		Productivity, ha·h^{-1}	Work consumption, hum-h·ha^{-1}	Fuel consumption, l·ha^{-1}
	Tractor	Machine	Tractor	Machine			
Catch crop sowing	212000	110000	2000	150	4.00	0.25	10.00
Disc stubble cultivation	75300	38500	2000	100	3.50	0.29	8.00
Ploughing	212000	40000	2000	600	2.45	0.41	15.20
Cultivation	80000	45000	2000	100	6,0	0,16	5.0
Fertilizing (x 2)	80000	110000	2000	150	30.00	0.03	3.00
Seeding	212000	110000	2000	150	4.00	0.25	10.00
Harrowing (x 2)	80000	20570	2000	72	4.80	0.21	3.00
Interrow cultivat. (x 2)	80000	49300	2000	48	2.40	0.42	5.00
Spraying (x 5 or 7)	212000	140000	2000	150	25.20	0.04	2.00
Water supply (x 5 or 7)	30000	14000	2000	150	25.20	0.04	2.00
Harvesting	330000	-	600	-	2.50	0.40	30.00
Grain transport	75300	14100	2000	150	2.40	0.42	8.00

Energy input and CO_2 emission assessment

The next step for the technology evaluation is calculating the energy consumption for the growing and harvesting technology implementation in MJ·ha^{-1}. Several authors [8; 9] recommend to calculate energy consumed E (1) for the process as the sum of the different energy inputs: E_1 – direct energy input for human labour (2), E_2 – indirect energy, used for production and supply of the machineries (3), E_3 – direct energy consumption for the usage of machineries (fuel) (4), E_4 – indirect energy consumption for fertiliser and pesticide production and supply (5), E_5 – indirect energy, used for the production and supply of seed (6).

$$E = E_1 + E_2 + E_3 + E_4 + E_5 \quad (1)$$

$$E_1 = S_{hl} * e_{hl}, \text{ MJ·ha}^{-1}, \quad (2)$$

where S_{hl} – spent human labour per hectare, h·ha^{-1};
e_{hl} – energy equivalent of human labour, MJ·h^{-1}.

$$E_2 = \frac{m * k_e}{T_\Sigma * W}, \text{ MJ·ha}^{-1} \quad (3)$$

where m – weight of machine or tractor, kg;
k_e – conversion equivalent, MJ·kg^{-1};
T_Σ – working time per machine or tractor, h;
W – machine productivity, ha·h^{-1}.

$$E_3 = S_f * e_f, \quad (4)$$

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

$$E_4 = S_{fert1} * e_{fert1} + S_{fert2} * e_{fert2} + S_{pest} * e_{pest}, \quad (5)$$

where S_{fert1} – rate of fertilizers (M1), kg·ha^{-1};
S_{fert2} – rate of fertilizers (M2), kg·ha^{-1};
e_{fert1} – energy equivalent of fertilizers (M1), MJ·kg $_N$$^{-1}$;
e_{fert2} – energy equivalent of fertilizers (M2), MJ·kg $_{K2O}$$^{-1}$;
S_{pest} – rate of pesticides, kg·ha^{-1};
e_{pest} – energy equivalent of pesticides, MJ·kg^{-1}.

$$E_5 = S_{s1} * e_{s1} + S_{s2} * e_{s2}, \quad (6)$$

where S_{s1} – rate of seeds (preseeding), kg·ha^{-1};
e_{s1} – energy equivalent of seeds (preseeding), MJ·kg^{-1};
S_{s2} – rate of seeds (seeding), kg·ha^{-1};
e_{s2} – energy equivalent of seeds (seeding), MJ·kg^{-1}.

Different coefficients were used for the calculation of energy inputs mentioned in the formulas above: e_{hl} = 2.3 [8], k_e = 142.1 [9], e_f = 56.31 [10], e_{pest} = 5.71 [6; 11; 12] – as the average number per kg/l pesticide product used in T3], e_{s1} = e_{s2} = 14.7 [13]. The coefficient was looked up in many literature resources, choosing the most appropriate for this process, region and other circumstances.

An important parameter for the evaluation of technologies is GHG CO_2eq emissions. The calculation uses the methodology recommended by the authors [6; 10], where total GHG emissions are calculated as the sum C (7) of emissions: C_1 – emissions raised from the production and supply of the machinery (8), C_2 – emissions raised from fuel used to operate the machinery (9), C_3 – emissions from the production and supply of fertilisers and pesticides (10), C_4 – seed production and supply emissions (11).

$$C = C_1 + C_2 + C_3 + C_4, \quad (7)$$

$$C_1 = \left(\frac{m_t}{L_{\Sigma t}} k_t + \frac{m_m}{L_{\Sigma m}} k_m \right) * F, \quad (8)$$

where m_t – weight of tractor, kg;
m_m – weight of machine, kg;
$L_\Sigma t$ – total number of working years per tractor, h;
$L_\Sigma m$ – total number of working years per machine, h;
k_t – tractor overall emission factor, kg CO_2eq·kg^{-1};
k_m – machine overall emission factor, kg CO_2eq·kg^{-1};
F – load per year per machine or tractor, ha yr^{-1}.

$$C_2 = S_f * k_f, \quad (9)$$

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

$$C_3 = S_{fert1} * k_{fert1} + S_{fert2} * k_{fert2} + S_{pest} * k_{pest}, \quad (10)$$

where S_{fert1} – rate of fertilizers (M1), kg·ha^{-1};
$S_{fert\,2}$ – rate of fertilizers (M2), kg·ha^{-1};

k_{fert1} – emission factors of fertilizers 1, $CO_2eq \cdot kg^{-1}$;
k_{fert2} – emission factors of fertilizers 2, $CO_2eq \cdot kg^{-1}$;
S_{pest} – energy rate of pesticides, $MJ \cdot ha^{-1}$;
k_{pest} – emission factors of pesticides, $CO_2eq \cdot MJ^{-1}$.

$$C_4 = S_{s1} * k_{s1} + S_{s2} * k_{s2}, \quad (11)$$

where S_{s1} – rate of seeds 1, $kg \cdot ha^{-1}$;
S_{s2} – rate of seeds 2, $kg \cdot ha^{-1}$;
k_{s1} – emission factors of seeds1, $CO_2eq \cdot kg^{-1;}$
k_{s2} – emission factors of seeds 2, $CO_2eq \cdot kg^{-1}$.

Different coefficients were used for the calculation of emissions mentioned in the formulas above: $k_t = 14.41$ [9], $k_m = 10.23$ [9], $k_f = 3.36$ [14], $k_{fert1} = 0.68$ [15], $k_{fert2} = 4.57$ [6] $k_{pest} = 0.069$ [6], $k_{s1} = 0.005$ [16], $k_{s2} = 0.91$ [16].

All equipment used in the process is listed in Table 3. The farm mostly has 8 till 15 years old tractors or other machinery. For the harrowing and inter-row cropping new equipment was applied and input data was applied for the economic and environmental assessment. For economical calculations the age of the equipment was not taken into account.

Table 3

Input data for calculation of energy (MJ) and GHG emissions (CO_2eq) of field bean growing technologies T1; T2; T3

Working operation (number of operations)	**Tractor**	**Machinery** (working width, m)	**Weight, kg**		**Prod.** ***W*, ha·h⁻¹**	**Working time**		**Load, ha year**
			m_t	m_m		T_Σ, hours	L_Σ, years	
Catch crop	JD8335	Horsch Focus, (6)	13000	9500	4.0	1500	10	600
Disc stubble cultivation	JD6920	Kokerling, (6)	5880	9000	3.5	1000	10	350
Ploughing	JD8335	Kverneland (2,8)	13000	3700	2.45	6000	10	600
Cultivation	JD6830	Bednar (8)	5800	7760	6.40	1000	10	640
Fertilizing (x 2)	JD6830	Rauch Accent, (36)	5880	4600	36.0	1500	10	4500
Seeding	JD8335	Horsch Focus, (6)	13000	9500	4.0	1500	10	600
Harrowing (x 2)	JD6830	Einboeck, (6)	5880	620	4.8	720	10	345
Interrow cultivation (x 2)	JD6830	Chopstar, (6)	5880	1650	2.4	1500	10	480
Spraying (x 5 or 7)	JD8335	Amazone, (36)	13000	8665	25.2	1500	10	3780
Water supply (x 5 or 7)	JD6900	Cask, 14 t	5390	4000	22.0	1500	10	3780
Harvesting	-	JDS685i (9)	-	18700	2.5	9000	15	1500
Grain transport	JD6920	Umega, 14t	8400	4450	2.3	1500	10	1500

Results and discussion

In 2020, chemical weed control was highly efficient. Mechanical weed control was less efficient due to the presence of volunteer oilseed rape plants that significantly increased both fresh and dry mass of the weeds [17]. In 2021, the difference between the chemical and mechanical weed control was less pronounced, while volunteer oilseed rape was still dominating in the treatments where mechanical weed control was used. The effect of mouldboard ploughing on weed control differed between the years. In 2020, the number and total mass of weeds per square meter was lower in the treatments where mouldboard ploughing was used, but in 2021 it was opposite in the treatments where mechanical weed control was used. In general, during the seasons 2020 and 2021 the presence of the higher fresh and dry mass of the weeds in mechanical control variant (T3) did not affect the yield and quality of the field beans. Comparing the yield and quality of the yield between technologies T1, T2 and T3 no significant differences were found. That means, that mechanical treatment is quite competitive to herbicides in field bean growing technologies, provided that weed control is efficient in the entire crop rotation cycle.

Economics

The field bean production costs for the technologies T1, T2, T3, calculated using the production cost and energy consumption data, were 845.64, 861.13 EUR 771.40 ha^{-1}, accordingly. Due to the large volume of calculation steps, the calculation results by positions are shown in Table 4 only for T1 technology. The results for all three technologies by positions are shown in Figure 1. In the case of T1 technology, more than half of the total cost is accounted for by the use of machinery, the cost of fertilizers and pesticides is about 22%, and the cost of seed is about 20% (Table 1). The cost structure and total costs were similar for T2 technology. T3 technology, on the other hand, did not use harrowing and row cultivation, so it had lower operational costs, but higher costs for pesticide application. Despite the increase in spraying and chemical costs, T3 technology was the most advantageous.

Table 4

Calculation of field bean production costs in T1 technology

Working operation (number of operations)	Operational costs, EUR·ha^{-1}				
	Amortization costs	Maintenance and repair costs	Fuel	Salary	Total
Catch crop	18.53	18.53	7.60	2.25	46.91
Disc stubble cultivation	11.05	11.05	6.08	2.57	30.76
Fertilizing (x2)	2.45	2.45	2.28	0.30	7.49
Seeding	18.53	18.53	7.60	2.25	46.91
Harrowing (x2)	5.98	5.98	2.28	1.88	16.12
Interrow cultivation (x2)	3.74	3.74	1.52	0.36	9.35
Spraying (x5)	42.84	42.84	3.80	3.75	93.22
Water supply (x5)	3.74	3.74	1.52	0.36	9.35
Harvesting	0.37	0.37	1.52	0.36	2.63
Grain transport	14.67	14.67	22.80	3.60	55.73
Operational costs					491.75
Ferilizer and pesticide costs					187.39
Seed costs (seeds: catch-crop; field beans)					166.50
Total costs, EUR·ha^{-1}					**845.64**

Difference in pesticide costs (materials plus operational costs) was 89.73 EUR, which is less than the cost of 2 harrowing and 2 interrow cultivations (T2).

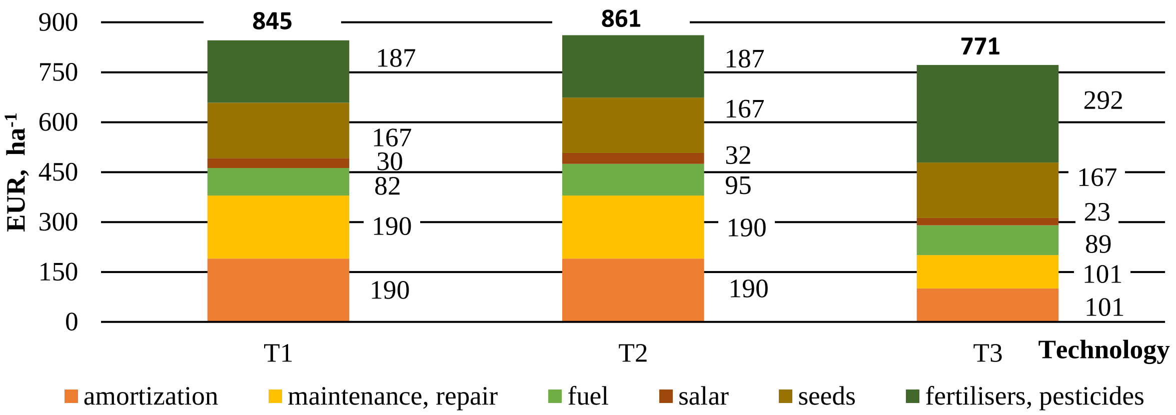

Fig. 1. **Economic expense calculations of field bean growing technologies**

It should be noted that the cost of harrowing operations amounts to 16.12 EUR, but of interrow cultivation to 93.22 EUR. If it were possible to use only harrowing for mechanical weed control, the technology would be more economically feasible, however, the efficiency of weed control should be checked.

Energy Input and CO*2 *emissions

The amount of energy consumed for the production and delivery of the used equipment E_2, MJ·ha^{-1} was calculated using the formula (3) and the input data given in Table 3. The emissions C1 for the production and delivery of the used equipment, kg·ha^{-1} for each technology, were calculated using the formula (8) and the data from Table 3. The results of the calculations are shown in Table 5.

The calculations of the other components of energy input and CO_2 emissions identified in formulas (1) and (7) (human labour, fuels, fertilizers, pesticides) were based on the formulas (4)-(6) and (9)-(11). Consumption data of fertilizers, pesticides, etc. for these calculations can be found in Tables 1 and 2, the coefficients used in the formulas can be found in rows after the last formula. Data on the amount of energy consumed for each technology and CO_2 emissions generated by each operation type are presented in Table 5 and in Figures 2 and 3 by splitting into components.

Table 5

Energy input and GHG emission calculation by operation in different technologies

Working operation (number of operations)	T1		T2		T3	
	MJ h^{-1}	CO_2 h^{-1}	MJ h^{-1}	CO_2 h^{-1}	MJ h^{-1}	CO_2 h^{-1}
Catch crop	3018	89	3018	89	3018	89
Disc stubble cultivation	835	88	0	0	0	0
Ploughing	0	0	1198	82	1198	82
Cultivation	0	0	462	42	462	42
Fertilizing (x2)	1270	137	1270	137	1270	137
Seeding	5223	463	5223	463	5223	463
Spraying (x5 or 7)	943	84	943	84	2059	168
Water supply	673	51	673	51	942	72
Harrowing (x2)	408	73	408	73	0	0
Inter-row cultivation (x2)	1009	210	1009	210	0	0
Harvesting	1927	113	1927	113	1927	113
Grain transport	653	73	653	73	653	73
Total	**15958**	**1380**	**16782**	**1417**	**16751**	**1239**

The calculation of operations presented in Table 5 also takes into account spent materials such as seed, fuel and pesticides, both energy input and GHG emissions. It can be seen that the most energy-intensive operations are sowing of catch-crop and field beans. This can be explained by the fact that seed energy input is based on the kcal of the seeds and supplemented with the energy amount for the seed dressing. The methodology used in this study does not suppose calculation of energy input, which was invested to growing technology of field beans or catch crop, therefore these numbers are quite high. As we see, the other energy consuming operations are harvesting and fertilizing operations. In turn, CO_2 emissions were highest for the seeding and fertilizing, but for the technology T3 one of the highest emission contributors are spraying operations (7 sprayings). In general, three herbicide applications accounted for 7% of CO_2 emissions in the T3 cycle, but harrowing with interrow cultivation accounted for 20% in the T1 cycle.

The energy input needed to implement the technological cycles is nearly the same in all three technologies (Fig. 2). The differences between the analysed technological cycles are minor, amounting to 5%, the T1 technology is less energy demanding. This is due to the fact that it does not include ploughing operation, which is substituted with disc stubble cultivation. On the other hand, the largest specific weight between components in all technologies is for seed and fuel contribution, each being 38-42% of the total energy input in all technologies.

We found no other studies on the energy input in bean cultivation, but the energy input for wheat cultivation has been calculated as 13679 MJ·ha^{-1} in the United States [18], and 8060 - 9300 MJ·ha^{-1} in Canada [19]. In Lithuania, however, the energy input has been studied in the cultivation of beet [20] and was calculated as 27844 MJ·ha^{-1}. Our estimation of energy consumption in field bean cultivation falls between that of winter wheat and sugar beet, which is an energy-intensive culture. Some authors indicate a 20-30% share of fuel in total energy input.

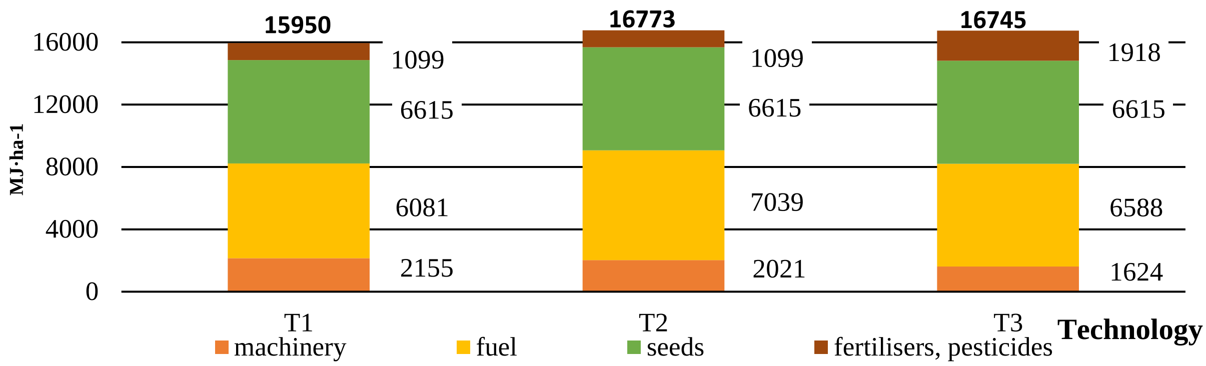

Fig. 2. **Technology energy input, calculation by components**

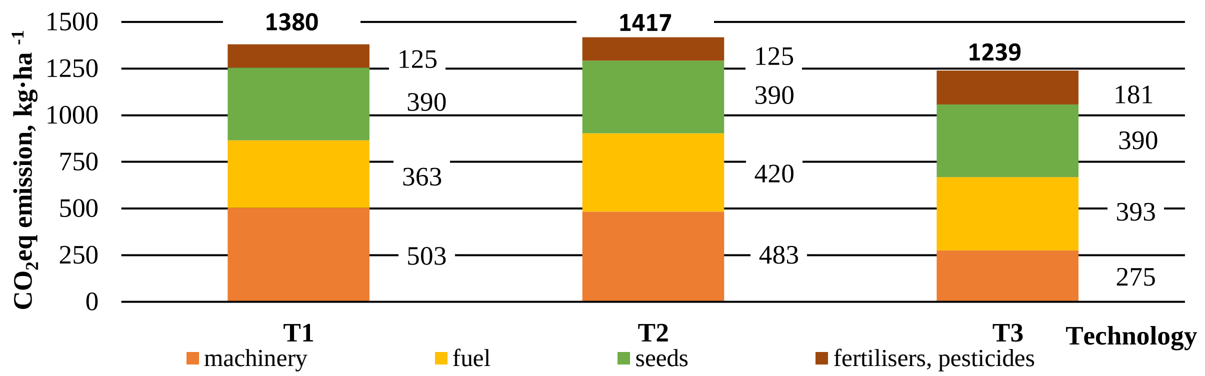

Fig. 3. **GHG emissions in different technologies, calculation by components**

Figure 3 shows the overall GHG emissions resulting from technology implementation and their distribution by components. The smallest emissions come from the technology T3 and are approximately by 11% and 14% lower than in T1 and T2, respectively. This is due to replacing the mechanical weed control with a more productive operation, spraying. When assessing emissions by components, the highest specific weight in all technologies is for seed and fuel collateral, each of these components in all technologies representing 26-32% of the total amount of GHG emissions. As previously, T3 that uses a more productive method of weed control, has the lowest emissions from machinery, as well as the lowest total emissions.

Analysing other studies on the amount of GHG emissions, it can be concluded that the emissions vary widely depending on different circumstances. In the data from Sweden, Greece, USA and Spain [21-24] the figures for the GHG emission assessment vary from 252 to 1173 kg·ha^{-1}. The factors that affect the estimates are the variety of field beans, the amount pesticides and fertilizers applied, the number of operations made, whether seed production was excluded from the life cycle analysis. In an aggregated analysis of the quantities of GHG emissions used in Denmark, Italy and Australia in legume-wheat-growing technologies, the results varied from 750 to 2396 kg·ha^{-1} [25]. In a study wheat growing technologies in the various regions of Denmark, the authors indicate the quantity of GHG emissions 1939-2003 kg·ha^{-1} [5]. Results of our calculations (Fig. 3) are comparable with the results of the other studies.

To better compare the characteristics of the three technologies studied, the economic efficiency should be compared alongside the energy input and GHG emissions. These characteristics are summarized in Table 6.

Table 6

Comparison of costs, energy input and GHG emissions in the three technologies

Technology	Costs, EUR·ha^{-1}	Energy input, MJ·ha^{-1}	GHG emissions, CO_2eq·kg·ha^{-1}
T1	845,6	15958.1	1380.2
T2	861,1	16782.1	1417.1
T3	771,4	16751.2	1239.2

As you can see, the production costs in T3 are by about 9% lower compared to the next cheapest technology T1, as well as the lowest GHG emissions (Table 6). This technology includes the traditional soil tillage method (mouldboard ploughing) and chemical weed control. Because of the lower costs, this technology is widely used on farms. The technological cycle T1, using reduced tillage and mechanical weed control, can be assessed as quite competitive. The T2 technology is at a disadvantage for all comparable parameters, it combines traditional soil tillage with mechanical weed control.

With the reinforcement of the ecological requirements for agriculture, the calculation of energy input and GHG emissions could serve as additional assessment criteria by selecting the production technology for the farm. However, the environmental impact of pesticide use has yet to enter the equation.

Conclusions

1. Taking into account the economic aspects and CO_2 emission indicator, it can be stated that at the moment chemical weed control (T3) performs better than mechanical weed control (T1, T2), but there is no methodology designed to compare the environmental and toxicological impact of pesticides with CO_2 emission load.
2. The GHG emissions vary moderate between crop production technologies (highest difference between T2 and T3 is 14%) depending on the number of field operations, technical parameters of the machinery, pesticides and fertilizers applied. It can be concluded that spraying should be well justified. The GHG emissions are minimized when fewer spraying operations are performed with pesticides that are more effective.
3. The energy investment gap between technologies T1, T2 and T3 is negligible, between technologies with 15958 $MJ \cdot ha^{-1}$, 16782 $MJ \cdot ha^{-1}$, 16751 $MJ \cdot ha^{-1}$ accordingly.
4. Mechanical weed control is quite competitive to herbicide use in field bean production. Further field trials are required to see the effect after 5 years of pesticide use reduction.
5. The results of this study per energy input and GHG emissions can serve as additional criteria for farmers in their choice of technologies.

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References

[1] Theoretical Aspects of Gross Coverage Calculation [online] [25.01.2022]. Available at: http://new.lkc.lv/sites/default/files/baskik_p/pielikumi/ (In latvian)

[2] Kopiks N., Viesturs D., Balode R. Method for the analysis of field crop production technologies. Proceedings of the Latvia University of agriculture Nr.16 (293), 1998), B – technical sciences, pp. 129.-135., Jelgava.

[3] Novakovska I., Bulgakov V., Rucins A., Dukulis I. Analysis of soil tillage by ploughs and optimistion of their aggregation. // 17th International scientific conference Engineering for rural development: proceedings, Jelgava, Latvia, May 23 - 25, 2018/Latvia University of Life Sciences and Technologies. Faculty of Engineering. Latvian Academy of Agricultural and Forestry Sciences. Jelgava, 2018. Vol. 17, pp.335-341. ISSN 1691-597.

[4] Asejeva A., Kopiks N., Viesturs D.. The choice of technological variants of soil tillage and cultivation for the growing of cereals. Proceedings of the International scientific conference Economic science for rural development, Academy of Agricultural and Forestry sciences of Latvia.

Latvia University of Agriculture. - Jelgava, 2007. - Nr.13: Primary and secondary production, consumption, pp. 78- 84.

[5] Elsgaard L., Olesen J.E., Hermansen J.E. et al. Regional greenhouse gas emissions from cultivation of winter wheat and winter rapeseed for biofuels in Denmark, Acta Agriculture Scandinavica, 2013., Section B – Soil &Plant Science, 63:3, 219-230, DOI: 10.1080/09064710.2012.751451.

[6] Audsley E., Stacey K., Parsons D. J., Williams A.G.. Estimation of the greenhouse gas emissions from agricultural pesticide manufacture and use. Cranfield University Cranfield Bedford MK43 0AL. Technical Report August 2009, p.20. DOI: 10.13140/RG.2.1.5095.3122.

[7] Kazlauskas M., Bručiene I., ˙A. Jasinskas, Šarauskis E. Comparative Analysis of Energy and GHG Emissions Using Fixed and Variable Fertilization Rates. Agronomy 2021,11, 138, p. 19. DOI: 10.3390/agronomy11010138.

[8] Kolarikova M., Ivanova T., Havrland B., Amonov K. Evaluation of sustainability aspect – energy balance of briquettes made of hemp biomass cultivated in Moldova. Agronomy Research 12(2), 2014, pp. 519-526.

[9] Supplementary material: The GHG emissions of machinery from manufacture, transportation and repair and maintenance. Sustainability 2019, 11, 5015; doi:10.3390/su11185015 www.mdpi.com/journal/sustainability.

[10] Gundogmus E., Bayramoglu Z. Energy Input Use on Organic Farming: A Comparative Analysis on Organic versus Conventional Farms in Turkey. Journal of Agronomy, 5, 2006. pp. 16-22. DOI: 10.3923/ja.2006.16.22 [online] [25.01.2022]. Available at: https://scialert.net/abstract/?doi = ja.2006.16.22 .

[11] Tzilivakis J., Warner D. J., May. M. J. et al. An assessment of the energy inputs and greenhouse gas emissions in sugar beet (Beta vulgaris) production in the UK, Agricultural Systems, Volume 85 (2), 2005, pp. 101-119. DOI: 10.1016/j.agsy.2004.07.01522.

[12] The Bio Grace GHG calculation tool. [online] [22.01.2022]. Available at: https://www.biograce. net/content/ghg calculation tools/recognised tool

[13] Lal B., Gautam P., Nayak A.K. et. al. Energy and carbon budgeting of tillage for environmentally clean and resilient soil health of rice-maize cropping system, Journal of Cleaner Production, Volume 226, 2019, pp. 815-830, ISSN 0959-6526, DOI: 10.1016/j. jclepro.2019.04.041. [online] [22.01.2022]. Available at: https://www.sciencedirect.com/science/article/pii/S0959652619311114

[14] Elsgaard L. Greenhouse gas emissions from cultivation of winter wheat and winter rapeseed for biofuels and from production of biogas from manure. According to the Directive 2009/28/EC of the European Parliament on the promotion of the use of energy from renewable sources. 28/07/2015 – Updated. [online] [22.01.2022]. Available at: https://pure.au.dk/ws/files/90330359/VE report revised update 2015 revised 28.07 submitted.pdf

[15] Jenssen T.K., Kongshaug G. Energy consumption and greenhouse gas emissions in fertiliser production. Proceedings No. 509, 2003. International Fertilizer Industry Association, 75008 Paris. ISBN 0 85310 145 0, (ISSN 1466-1314) p. 29.

[16] Gustavo G.T. Camargo, Matt R. Ryan, Tom L. Richard. Farm Energy Analysis Tool (FEAT). Version 1.1, 2012, Pennsylvania State University. [online] [22.01.2022]. Available at: https://www.ecologicalmodels.psu.edu/agroecology/feat/download.htm

[17] Putniece G., Sanžarevska R., Ņečajeva J. (2021) Implementing mechanical weed control to reduce herbicide use in Faba bean. Zinātniski praktiskā konference "LĪDZSVAROTA LAUKSAIMNIECĪBA", 25.–26.02.2021., LLU, Jelgava, Latvija pp. 27-32.

[18] Amenumey S.E., Capel P.D. Fertilizer Consumption and Energy Input for 16 Crops in the United States. Natural Resources Research, September 2014. [online] [22.01.2022]. Available at: https://www.researchgate.net/publication/264350545. DOI: 10.1007/s11053-013-9226-4. 30

[19] Zentner R. P., McConkey B. G., Stumborg M. A. et. al. Energy performance of conservation tillage management for spring wheat production in the brown soil zone. CANADIAN JOURNAL OF PLANT SCIENCE, April 1998, p. 553- 563.

[20] Bručiene I., Aleliunas D., Šarauskis E., Romaneckas K.. Influence of Mechanical and Intelligent Robotic Weed Control Methods on Energy Efficiency and Environment in OrganicSugar Beet Production. Agriculture 2021,11, 449. DOI: 10.3390/agriculture11050449

[21] Tidåker P., Karlsson Potter H., Carlsson Get al. Towards sustainable consumption of legumes: How origin, processing and transport affect the environmental impact of pulses, Sustainable Production and Consumption, Volume 27, 2021, pp. 496-508, ISSN 2352-5509, DOI: 10.1016/j.spc.2021.01.017

[22] Abeliotis K. Abeliotis V. Detsis et al Life cycle assessment of bean production in the Prespa National Park, Greece, J. Clean Prod., 41, 2013, pp. 89-96

[23] Aguilera E. Aguilera, G. Guzmán, et al. Greenhouse gas emissions from conventional and organic cropping systems in Spain. I. Herbaceous crops Agron. Sust. Dev., 35, 2015, pp. 713-724

[24] Arathamesh A., Bandekar, Ben Putman, et al., Cradle-to-grave life cycle assessment of production and consumption of pulses in the United States, Journal of Environmental Management, Volume 302, Part B, 2022, 114062, ISSN 0301-4797, DOI: 10.1016/j.jenvman.2021.114062.

[25] Popluga D. Linking Latvia's agricultural greenhouse gas emission limit reduction cost curves (MACC) with carbon sequestration and storage in arable land, perennial grasslands and wetlands. Report on the implementation of the research project. Decision Nr.: 10.9.1-11/18/929-e. LLU, Jelgava, 2018., pp. 47-73. (In Latvian).