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The Energy and Environmental Evaluation of Maize, Hemp and Faba Bean Multi-Crops

Kęstutis Romaneckas *, Austėja Švereikaitė, Rasa Kimbirauskienė, Aušra Sinkevičienė and Jovita Balandaitė

Department of Agroecosystems and Soil Sciences, Agriculture Academy, Vytautas Magnus University, Studentu Str. 11, LT-53362 Akademija, Kaunas District, Lithuania; austeja.svereikaite@stud.vdu.lt (A.Š.); rasa.kimbirauskiene@vdu.lt (R.K.); ausra.sinkeviciene@vdu.lt (A.S.); jovita.balandaite@vdu.lt (J.B.)
* Correspondence: kestutis.romaneckas@vdu.lt; Tel.: +370-656-300-44

Abstract: Agriculture uses a lot of fuel, fertilizers, pesticides and other substances, while emitting large amounts of GHGs. It is important to optimize these inputs and outputs. One such way is by increasing crop biodiversity. For this reason, single crops and mixtures of maize, hemp and faba bean as binary and ternary crops were investigated at the Experimental Station of Vytautas Magnus University, Lithuania. The results showed that consumption of diesel fuel was 31–46% higher than in single and 22–35% higher than in binary cultivations was found in a ternary crop. This had influence on the highest energy input of near twice higher than in maize and hemp single crops and maize+hemp binary crop, but similar with binary crops with faba bean. Despite this, the productivity of the ternary crop and, at the same time, the energy output were 2–5 times higher than in other treatments. This compensated for higher energy inputs and the energy efficiency ratio. In the ternary crop, energy productivity was from 1.1 to 2.8 times higher and net energy was 1.9–5.3 times higher than in other tested cultivations. The highest total GHG emissions were obtained in binary maize+hemp and maize+faba bean cultivations (1729.84 and 2067.33 CO_{2eq} ha^{-1}). Ternary cultivation with the highest energy inputs initiated average GHG emissions of 1541.90 kg ha^{-1} CO_{2eq}. For higher efficiency, the ternary crop could be sown and harvested in one machine pass. Faba beans should be included in ternary crops, as their biomass makes up a significant part of the total biomass produced. We recommend reviewing the intercropped faba bean seeding rates, as faba bean seeds have a high energy input equivalent.

Keywords: *Zea mays* L.; *Cannabis sativa* L.; *Vicia faba* L.; multicultivations; energy indices; CO_{2eq}

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1. Introduction

In agriculture, energy consumption and environmental pollution are points that need improvement. Tillage technologies are one of the most energy-intensive and expensive technological operations [1]. Reversible tillage technologies consume between 29 and 59% of total diesel fuel in the technological process [2,3]. Fertilizer production and use account for the majority of energy expenditure (about 50%) in field crop production in Europe [4]. The production of nitrogen fertilizer is a particularly energy-intensive process; compared to the production of phosphorus and potassium fertilizers, about 10 times more energy is consumed [5].

Agriculture's direct contribution to GHGs are estimated to be 10−15% of total anthropogenic GHG emissions, of which non-CO_2 anthropogenic GHG emissions consist of 48%. Sustainable agriculture, which reduces greenhouse gas (GHG) emissions, can contribute to climate change mitigation [6]. Also, organic agriculture, in contrast to traditional farming, is associated with a lower average of GHG emissions per hectare [7].

There is still no formal agreement on a methodology for calculating greenhouse gas (GHG) emissions from crop production systems and there is still a need to improve the sustainability of agrotechnologies. It is difficult to evaluate total carbon inputs in agrotechnologies. It is useful to convert different inputs into carbon dioxide emissions equivalent for agriculture [8].

The multi-cropping of biomass crops one of the ways to increase energy use efficiency, GHG emission mitigation and the protection of soil and water. Reducing dependence on imported energy and energy products is the goal of the European Union's energy policy, which promotes energy efficiency measures and the integration of renewable energy sources (RES) [9]. The European Union wants to increase the energy supply from alternative sources by 2030 (up to 45%). Biomass is an acceptable fuel because it contains very little or even no toxic substances such as sulfur and heavy metals, usually found in fossil fuels and emitted into the air by combustion [10]. However, despite the enormous hidden potential in this area, the cultivation of multi-crops has still not been sufficiently studied [11,12]. Multi-cropping is a type of crop cultivation where several species of plants are grown at the same place and time. Multi-cropping ensures farming sustainability and successful crop productivity [13]. Multi-cropping can also reduce the spread of diseases, pests and weeds as well as need for mineral fertilizers, and maintain soil fertility and quality, making it easier for plants to grow under adverse conditions [14]. It is important to understand that the number of plants that can be cultivated as multi-crops is quite large, that all crops have a different function, and that their benefits are not the same. In order to achieve the maximum harvest result, the advantages of each multilayer plant must be exploited [15].

Maize, industrial hemp and faba bean might be effective companions in energy multi-crops because maize is a crop with high potential for biomass production. Today, maize is one of the most important and productive crops in the world, with more than 206 million hectares being cultivated in 2021. It can be used for the production of feed, biofuels, synthetic plastics, chemical compounds, etc. [16,17]. Industrial hemp is also able to produce high biomass production yields with a relatively low water amount [18]. Faba beans are mainly used for food, animal feed and soil improvement, but they can be used for energy purposes by converting biomass into pellets and using them as medium-to-low-power boilers [19].

The aim of this study was to evaluate the biomass production capacities of differently biodiversified multi-crops; to analyze the possibilities of current machinery; to evaluate the inputs of energy for main materials, fuels, working time and biomass energy outputs; and to ascertain the impact of current technologies on the GHG emissions according to their CO_2 equivalents. We hypothesize that cultivation of a ternary crop not only produces more plant biomass, but also uses energy more efficiently, and GHG emissions are lower.

2. Materials and Methods

2.1. Experimental Site

A stationary field experiment was conducted in 2020–2022 at the Experimental Station of Vytautas Magnus University, Agriculture Academy. In this study, data of crops biomass from 2020 are presented because the yield was the highest and most suitable for fuel production in comparison with the continued cropping of 2021 and 2022.

The experimental soil used was Planosol (Endohypogleyic-Eutric, Ple-gln-w) [20], with a nearly neutral pH, rich in available phosphorus and magnesium, an average level of potassium and a low level of total nitrogen.

Lithuania is characterized by excess humidity. At the experimental site, the annual average precipitation rate varies from 600–650 mm to approx. 300–400 mm of precipitation per vegetative season. In January, negative temperatures are recorded most often. In July, droughts occur more and more often, and the peak of precipitation moves to the beginning of August. In the 2020 vegetative season, average air temperatures were the same as the long-term average, but rainfall was 10 times less. In May, weather was colder, but with excess humidity (Table 1). June was warmer than usually, but the precipitation rate was approximately 30% higher than the long-term climatic rate.

Table 1. Average air temperatures and precipitation rates. Kaunas Meteorological Station, 2020.

Months	Average Air Temperatures °C		Precipitation Rates mm	
	Monthly	Long-Term	Monthly	Long-Term
April	6.9	6.9	4.0	41.3
May	10.5	13.2	94.4	61.7
June	19.0	16.1	99.3	76.9
July	17.4	18.7	60.4	96.6
August	18.7	17.3	92.8	88.9

July was colder than average and slightly arid, but August was warmer and a little more humid. In summary, it can be said that the vegetation conditions of the year were favorable for crop development, as moisture was usually sufficient.

2.2. Treatments and Agronomic Practice

Three types of cultivation, single, binary and ternary, are presented in Table 2.

Table 2. Crop bio-diversity.

Treatments	Cultivation	Abbreviation
Single crop	Maize	MA
	Hemp	HE
	Faba bean	FB
Binary crop	Maize + hemp	MA + HE
	Maize + faba bean	MA + FB
	Hemp + faba bean	HE + FB
Ternary crop	Maize + hemp + faba bean	MA + HE + FB

An experiment was performed with three replications on 21 experimental plots (sized 8 m^2). In 2019, the pre-crop of multicultivations was oat. In 2021–2022, cultivations were grown continuously.

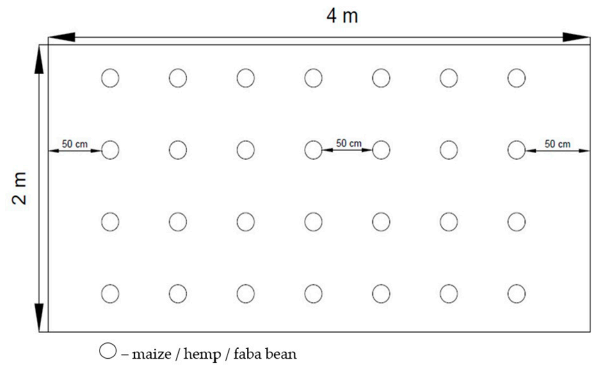
In autumn 2019, disc-cultivation and ploughing took place (Table 3). In spring 2020, cultivation took place in spring before sowing. In April, before seeding, the soil of the experiment was shallowly tilled. Before the seeding of the crop, plots were fertilized at a ratio of $N_{45}P_{45}K_{45}$ before seeding. Additional fertilization was not used.

Table 3. Single- and multi-cropping technological operations.

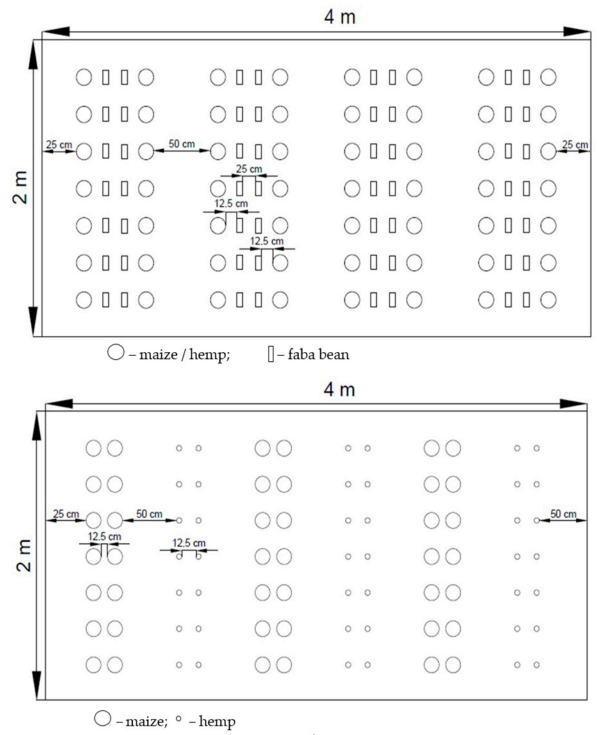
Technological Operation (Machinery/Depth/Material Rate)/Treatments	M	H	FB	M + H	M + FB	H + FB	M + H + FB
Stubble cultivation (depth 12–15 cm)	o	o	o	o	o	o	o
Deep ploughing	o	o	o	o	o	o	o
Pre-seeding cultivation	o	o	o	o	o	o	o
Fertilization (N_{45} P_{45} K_{45} kg ha^{-1})	o	o	o	o	o	o	o
One-pass conventional seeding of single crops	o	o	o	-	-	-	-
One-pass double seeding for binary crops	-	-	-	o	o	o	-
Two-pass ternary seeding	-	-	-	-	-	-	o
Interrow loosening (2–3 cm depth)	oo	oo	oo	oo	oo	oo	o
One-pass biomass harvesting (low harvester load)	o	-	o	-	o	-	-
One-pass biomass harvesting (high harvester load)	-	o	-	o	-	o	-
Two-pass biomass harvesting (high harvester load)	-	-	-	-	-	-	o

Notes: M—maize; H—hemp; FB—faba bean; M + H—maize + hemp; M + FB—maize + faba bean; H + FB—hemp + faba bean; M + H + FB—maize + hemp + faba bean. o—operation performed once; oo—operation performed twice.

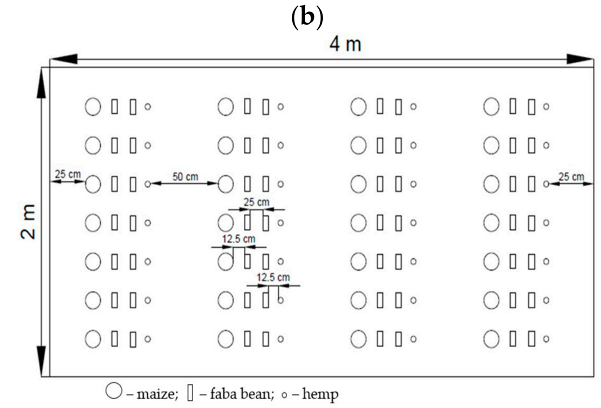
The experiment closely followed the modelled conditions, so the crops were sown manually according to predetermined schemes. The sowing schemes are shown in Figure 1.



(**a**)



(**b**)



(**c**)

Figure 1. The seeding schemes of single (**a**), binary (**b**) and ternary (**c**) cultivations.

According to the schemes of seeding, the seed rates are presented in Table 4. The idea of the experiment was to increase the usual seeding rates for more rapid weed control and higher biomass production potential. For a better balance of energy inputs, seeding rates could be decreased, especially for faba bean.

Table 4. Seeding rates (kg ha^{-1}) of differently biodiversified cultivations.

Crop/Treatments	M	H	FB	M + H	M + FB	H + FB	M + H + FB
Maize yield	63.5	-	-	68.8	90.7	-	36.2
Hemp yield	-	22.3	-	14.9	-	21.0	13.7
Faba bean yield	-	-	362.9	-	397.9	369.4	375.8

For the energy and environmental evaluation, we selected machinery that is mostly used in agriculture in Lithuania. The interrows of cultivations were mellowed 1–2 times. Pesticides were not used. In the experiment, crop biomass was cut by hand at the time of the faba beans' full maturity (short, 103-day vegetative period). The maize and hemp vegetative period was short for the highest biomass production, but in August, there was a deficit in plant biomass for fuel purposes in Lithuania.

In our calculations of energy and environmental evaluation of multi-cropping agrotechnology, we used the data normative of agricultural machinery from the Lithuanian Institute of Economics and Rural Development [21,22]. For our calculations, we used a field size of 2–10 ha. Tractor power varied from 45 to 102 kW; the power of the biomass harvester was 250 kW (Table 5). The data of mechanical seeders are provided in the calculations, where about 200 kg ha^{-1} of seeds were sown. Double sowing was carried out with a combined sowing machine, in which separate seed boxes or the sowing unit of the one next to it could be installed. For sowing in two passes, we provided both of the previously mentioned seeders. Of course, a ternary crop seeder can be made to seed such a crop in one pass, in which case the energy and environmental calculations change.

Table 5. Technical indicators of single- and multi-cropping operations.

Technological Operation	Machinery Power (kW)	Working Width (m)	Field Capacity (ha h^{-1})	Working Time (h ha^{-1})	Fuel Consumption (L ha^{-1})
Stubble cultivation-discing	102	4.00	2.21	0.45	8.2
Deep ploughing	102	1.75	0.80	1.25	24.1
Pre-sowing cultivation	102	7.00	4.56	0.22	6.4
One-pass conventional seeding (single crop)	45	3.00	1.41	0.71	4.0
One-pass double seeding (binary crop)	67	3.00	1.31	0.76	9.8
Two-pass seeding (ternary crop)	45 and 67	3.00	0.68	1.47	13.8
Fertilization	67	14.00	16.55	0.06	0.6
Interrow loosening	54	3.00	1.56	0.64	4.10
One-pass biomass harvesting (low harvester load)	250	3.00	1.82	0.55	19.19
One-pass biomass harvesting (high harvester load)	250	3.00	1.37	0.73	27.55
Two-pass biomass harvesting	250	3.00	0.68	1.47	46.74

A 6-furrow biomass harvester was chosen. Single and binary crops without hemp are classified as having low harvester load. For difficult conditions, we classified single and binary crops with hemp. Biomass harvesting in two passes was performed in ternary crops, in which the juicier upper part of the biomass was cut first, and the woodier lower part was cut in the second pass.

2.3. Methodology

Biomass productivity samples were taken in at least in 5 spots per each experimental plot and for each species of crop. Thirty-six samples were formed in total. Biomass was dried at a temperature of 105 °C to absolutely dry form. The results of the dried biomass are presented in this study.

A biomass chemical composition was tested in the laboratories of Lithuanian Research Centre for Agriculture and Forestry in Kaunas, Lithuania (Table 6). The biomass of crops is rich in elements important for biofuel production and plant nutrition (such as pellets or ash). These features were registered as patents for the production of fuel pellets from faba bean residues and ternary crop cultivation biomass at the Lithuanian National Patent Office [23,24].

Table 6. Biomass chemical composition.

Biomass Chemical Composition	M	H	FB	M + H	M + FB	H + FB	M + H + FB
pH	6.51	7.07	6.63	6.66	6.43	7.09	6.87
Total nitrogen %	0.92	0.64	2.12	0.84	1.48	1.22	0.98
Available phosphorus %	0.20	0.16	0.38	0.20	0.32	0.28	0.22
Available potassium %	1.20	0.76	0.78	0.98	1.04	0.98	0.87

Note: M—maize; H—hemp; FB—faba bean; M + H—maize + hemp; M + FB—maize + faba bean; H + FB—hemp + faba bean; M + H + FB—maize + hemp + faba bean.

Equivalents of energy inputs and outputs in single- and multi-crop biomass production are presented in Table 7.

Table 7. Energy equivalents in crop biomass production systems.

Indices	Energy Equivalent	Reference
Inputs:		
Human labor (MJ h^{-1})	1.96	[25]
Diesel fuel (MJ L^{-1})	56.3	[25]
Agricultural machinery (MJ h^{-1})	357.2	[26]
Seed of maize (MJ kg^{-1})	16.6	[25]
Seed of hemp (MJ kg^{-1})	25.0	[27]
Seed of faba bean (MJ kg^{-1})	21.0	[28]
N (MJ kg^{-1})	60.6	[25]
P_2O_5 (MJ kg^{-1})	11.1	[25]
K_2O (MJ kg^{-1})	6.7	[25]
Outputs:		
Maize biomass (MJ kg^{-1} dry matter)	17.7	[29]
Hemp biomass (MJ kg^{-1} dry matter)	16.6	[30]
Faba bean biomass (MJ kg^{-1} dry matter)	17.0	[31]

The energy ratio (energy use efficiency) and net energy were calculated based on the energy equivalents of agrotechnological inputs and outputs [32,33]. All agricultural technological operations, machinery and materials can also be evaluated as environmental impacts by CO_2 equivalent (Table 8).

Table 8. CO_2 equivalents in crop biomass production systems.

Inputs	CO_2 Equivalent	Reference
Diesel fuel (kg CO_{2eq} L^{-1})	2.76	[34]
Agricultural machinery (kg CO_{2eq} MJ^{-1})	0.071	[35]
Seed of maize (kg CO_{2eq} kg^{-1})	15.3	[36]
Seed of hemp (kg CO_{2eq} kg^{-1})	18.7	[26]
Seed of faba bean (kg CO_{2eq} kg^{-1})	0.99	[37]
N (kg CO_{2eq} kg^{-1})	1.30	[38]
P_2O_5 (kg CO_{2eq} kg^{-1})	0.20	[38]
K_2O (kg CO_{2eq} kg^{-1})	0.15	[38]

In our study, we calculated GHG emissions (kg CO_{2eq} ha^{-1}) by multiplying agrotechnological inputs by the CO_2 equivalents [38].

We used ANOVA from the statistical software SELEKCIJA (vers. 5.00, author: Dr. Pavelas Tarakanovas, Lithuanian Institute of Agriculture, Akademija, Kedainiu distr., Lithuania) for data analysis. An LSD test was performed. Letters mean significant differences between treatments at $p \leq 0.05$.

3. Results and Discussion

3.1. Energy Inputs

Energy consumption is an important factor in agriculture [39] because agrotechnologies use several different powerful machines for soil tillage, seeding, crop care and harvesting [32].

In this study, we analyzed the energy inputs and outputs of maize, hemp and faba bean multi-crop biomass production technologies. Our analysis includes human labor, fuel consumption, types of agricultural machinery, working time, seed and fertilizer needs. Energy output is related to the capacities of multi-crop biomass production (Table 9).

Table 9. Energy inputs of technological operations and materials in crop biomass production systems, MJ ha^{-1}.

Inputs	M	H	FB	M + H	M + FB	H + FB	M + H + FB
Human labor	8.8	9.2	8.8	9.4	9.0	9.4	11.0
Diesel fuel	3980.4	4447.7	3980.4	4774.2	4307.0	4774.2	5815.8
Agricultural machinery	1607.4	1678.8	1607.4	1714.6	1643.1	1714.6	2000.3
Seed of maize	1054.1	-	-	1142.1	1505.6	-	600.9
Seed of hemp	-	512.9	-	342.7	-	483.0	315.1
Seed of faba bean	-	-	7620.9	-	8355.9	7757.4	7891.8
N	2727.0	2727.0	2727.0	2727.0	2727.0	2727.0	2727.0
P_2O_5	499.5	499.5	499.5	499.5	499.5	499.5	499.5
K_2O	301.5	301.5	301.5	301.5	301.5	301.5	301.5
Total energy input	10,178.7	10,176.6	16,745.5	11,511.0	19,348.6	18,266.6	20,162.9

Note: M—maize; H—hemp; FB—faba bean; M + H—maize + hemp; M + FB—maize + faba bean; H + FB—hemp + faba bean; M + H + FB—maize + hemp + faba bean.

Analyzing the indicators of multi-cropping and other technological operations presented in Table 9, it was found that the lowest labor capacity was for the maize single crop (8.8 MJ ha^{-1}) and faba bean (8.8 MJ ha^{-1}). The highest capacity was for the ternary crop (11.0 MJ ha^{-1}) because of the wider agrotechnological operations.

Biodiesel has been gaining growing importance in terms of the environment and energy. Other researchers have obtained opposite trends in the high labor and fuel costs of growing bean crops [32]. Biodiesel can be produced from processed vegetable oils from different feedstocks like sunflower oil [40], rapeseed oil [41,42], soybean oil [43,44], palm oil [45] and hemp (Table 9).

In the presented experiment, the highest fuel consumption was obtained when growing the ternary crop (5815.8 MJ ha^{-1}), and the lowest in single maize (3980.4 MJ ha^{-1}) and faba bean (3980.4 MJ ha^{-1}). Ali et al. [46] stated that the highest energy consumption of diesel fuel accounted for about 54% of the total energy used for single faba bean cultivation.

Similar trends have been identified in agricultural machinery as well as in diesel fuel. The most intensive use of agricultural technique was found in the ternary (M + H + FB) crop (2000.3 MJ ha^{-1}). Compared to other crops, it was 14.3 to 19.6% higher (Table 9).

Maize (600.9 MJ ha^{-1}) and hemp (315.1 MJ ha^{-1}) seeds were the lowest in the ternary crop (M + H + FB) compared to other crops. The highest amount of energy from the seed of maize (1505.6 MJ ha^{-1}) was determined in the binary (M + FP) crop, and seed of hemp (512.9 MJ ha^{-1}) in the single (H) crop. The seed of faba bean (8355.9 MJ ha^{-1}) had the highest amount of energy input in the binary (M + FB) crop, and the lowest (7620.9 MJ ha^{-1}) in the single FB crop compared to other crops.

Fertilizer use has increased exponentially worldwide over the past few decades. The intensive use of mineral fertilizers and the use of conventional methods of fertilization have a negative impact on soil, the environment and human health [47]. In the presented experiment, the highest amount of energy input (2727.0 MJ ha^{-1}) was determined for N fertilizer, while the lowest (301.5 MJ ha^{-1}) was calculated for K_2O fertilizer (Table 9).

The total energy consumption was the highest (20,162.9 MJ ha^{-1}) in the ternary crop (M + H + FB), and the lowest (10,176.6 MJ ha^{-1}) in the single crop (H) (Table 9). The most energy was used on the ternary crop (M + H + FB) because more human labor was added, more diesel fuel is consumed and agricultural machinery was used several times. This is because single crops require much less energy than other multicultivations [48].

3.2. Biomass Productivity

Maize and hemp biomass are the main resources for biofuel production [49–51]. The highest biomass of maize was grown in a single cultivation—4461 kg ha^{-1}—and the lowest one in the ternary crop (1358 kg ha^{-1}) (Table 10) because the maize crop density in the ternary crop was more than twofold lower (about 134 thousand plants per ha) according to the seeding scheme. Maize with faba bean intercropping produced the second highest yield of biomass—3519 kg ha^{-1}. According to the findings of other scientists, maize mixed with *Fabaceae* crops warrants higher maize yields [52], but we came to the opposite conclusions [53].

Table 10. Single- and multi-crop dried biomass yields.

Biomass Yields and Composition	M	H	FB	M + H	M + FB	H + FB	M + H + FB
Total yield kg ha^{-1}	4461 c	9038 bc	9811 bc	12,197 b	7787 bc	10,974 b	22,928 a
Proportion of biomass components	-	-	-	1:4.1	1:1.2	1:0.2	1:5.3:10.6
Yields of separate components kg ha^{-1}:							
Maize yield	-	-	-	2373	3519	-	1358
Hemp yield	-	-	-	9824	-	8710	7239
Faba bean yield	-	-	-	-	4268	2264	14,331

Notes: M—maize; H—hemp; FB—faba bean; M + H—maize + hemp; M + FB—maize + faba bean; H + FB—hemp + faba bean; M + H + FB—maize + hemp + faba bean. Different letters (a, b, c) represent significant differences between treatments at $p \leq 0.05$.

The highest dried hemp biomass was in the binary hemp and maize crop (9824 kg ha^{-1}) and the lowest one was in the ternary crop (7239 kg ha^{-1}).

Faba bean, in companion to maize and hemp in the ternary crop, showed the best results (14,331 kg ha^{-1} of dried biomass) although the density of the faba bean crop in the crops of different diversifications varied little—from 560 to 614 thousand plants per hectare. In addition, the hemp and maize crop densities were the lowest in the ternary cultivation. Faba bean interacts less with rarer crops. Similarly, Ewansiha et al. [54] concluded that reducing the maize share increases the productivity of intercrops.

The significantly highest total dried biomass of crops was found in the ternary crop—22,928 kg ha^{-1} or 2–5 times higher than in the other tested single and binary cultivations (Table 10).

3.3. Fuel Consumption and Energy Indices

Diesel fuel consumption, energy input, energy output, energy efficiency ratio and net energy of the various mechanized technological operations for tillage, sowing, fertilizing and harvesting are presented in Table 11.

Table 11. Fuel consumption and energy indices of single- and multi-crop biomass production systems.

Treatments	Diesel Fuel Consumption L ha^{-1}	Energy Input MJ ha^{-1}	Energy Output MJ ha^{-1}	Energy Efficiency Ratio	Net Energy MJ ha^{-1}
M	70.7	10,178.7	78,959.7	7.76	68,781.0
H	79.0	10,176.6	150,030.8	14.74	139,854.2
FB	70.7	16,745.5	166,787.0	9.96	150,041.5
M + H	84.8	11,511.0	205,080.5	17.82	193,569.5
M + FB	76.5	19,348.6	134,842.3	6.97	115,493.7
H + FB	84.8	18,266.6	183,074.0	10.02	164,807.4
M + H + FB	103.3	20,162.9	387,831.0	19.23	367,668.1

Note: M—maize; H—hemp; FB—faba bean; M + H—maize + hemp; M + FB—maize + faba bean; H + FB—hemp + faba bean; M + H + FB—maize + hemp + faba bean.

The highest consumption of diesel fuel was found in the ternary crop (M + H + FB) (103.3 L ha^{-1}) due to more technological operations. When growing maize and faba bean single crops, diesel fuel consumption was the lowest at 70.7 L ha^{-1}, which is less than 1.5 times that of the ternary crop (M + H + FB). Šarauskis et al. [32] obtained the same trends with monocropped faba beans.

In the present experiment, the highest energy output (387,831.0 MJ ha^{-1}) was obtained from the ternary (M + H + FB) crop, and the lowest from the single maize crop (7859.7 MJ ha^{-1}).

In presented experiment, in the single maize crop, the energy efficiency ratio was 2.8 times lower compared to the ternary crop. The highest net energy (367,668.1 MJ ha^{-1}) was also obtained in the ternary crop. Other researchers have claimed that growing more plants in cultivation results in higher net energy [2]. Similarly, Ghazvineh at al. [55] found that in maize cultivation, the total energy consumption and output were 50.485 and 134.946 MJ ha^{-1}, respectively. Nitrogen fertilizers, electricity and diesel fuel consume the largest part of energy with 35.25 and 20 percent, respectively.

The single hemp crop produced 150,030.8 MJ ha^{-1} of energy (Table 11), while in Prade et al.'s [50] experiment, hemp produced 296,000 MJ ha^{-1} of energy, nearly 1.3 times less than in the ternary crop. In other experiments, green hemp consisted of nearly 286,500 MJ ha^{-1} of energy [30]. Teirumnieka et al. [56] highlighted that for short-term energy use, hemp cultivation could be a good alleviate, but for the long perspective, high-value-added products from hemp should be produced. Thus, a ternary multi-crop could improve single hemp cultivation with the addition of higher energy output and net energy.

3.4. Environmental Impact

Twenty-four percent of total net GHG emissions comes from forestry, agriculture and other land use (AFOLU) [57] or from 5.0 to 5.8 Gt CO_{2eq} per year (from 2000 to 2017) [58]. Efficient use of energy is one of the main requirements of sustainable agriculture [59]. All production processes need new innovative technologies to mitigate energy use, pollution and GHG emissions for sustainable development [60–63]. Pollution of the environment in agriculture relates with use of machinery, diesel, electricity, fertilizers, seeds and pesticides [64,65].

The GHG emissions for the agrotechnological inputs were recalculated into a CO_{2eq} system using the conversion equivalents (Table 12).

The highest amount of CO_{2eq} ha^{-1} from diesel fuel was obtained in the cultivation of the ternary M + H + FB crop (285.1 kg CO_{2eq} ha^{-1}), and the lowest in single maize (M) and faba bean FB—195.1 kg CO_{2eq} ha^{-1}—because diesel consumption was 1.2 to 1.5 times higher. Pishgar-Komleh et al. [60] estimated that the total GHG emissions from cucumber production was 82,724 kg CO_{2eq} ha^{-1}, with the highest emissions from diesel (61%), electricity (19%) and manure (14%).

Table 12. GHG emissions from single- and multi-crop biomass production systems.

Indices/Treatments	M	H	FB	M + H	M + FB	H + FB	M + H + FB
Diesel fuel (kg CO_{2eq} ha^{-1})	195.1	218.0	195.1	234.0	211.1	234.0	285.1
Agricultural machinery (kg CO_{2eq} ha^{-1})	0.32	0.33	0.32	0.34	0.33	0.34	0.40
Seed of maize (kg CO_{2eq} ha^{-1})	971.6	-	-	1052.6	1387.7	-	553.9
Seed of hemp (kg CO_{2eq} ha^{-1})	-	417.0	-	278.6	-	392.7	256.2
Seed of faba bean (kg CO_{2eq} ha^{-1})	-	-	359.3	-	393.9	365.7	372.0
N (kg CO_{2eq} ha^{-1})	58.5	58.5	58.5	58.5	58.5	58.5	58.5
P_2O_5 (kg CO_{2eq} ha^{-1})	9.0	9.0	9.0	9.0	9.0	9.0	9.0
K_2O (kg CO_{2eq} ha^{-1})	6.8	6.8	6.8	6.8	6.8	6.8	6.8
Total GHG emission (kg CO_{2eq} ha^{-1})	1241.32	709.63	629.02	1729.84	2067.33	1067.04	1541.90

Note: M—maize; H—hemp; FB—faba bean; M + H—maize + hemp; M + FB—maize + faba bean; H + FB—hemp + faba bean; M + H + FB—maize + hemp + faba bean.

The same trends presented in agricultural machinery. In the ternary crop, CO_{2eq} of agricultural machinery was 1.3 times higher compared to other cultivations. Seeds of maize (553.9 kg CO_{2eq} ha^{-1}) and hemp (256.2 CO_{2eq} ha^{-1}) had the lowest emissions in the ternary M + H + FB crop compared to the other crops. Maize seeds (1387.7 CO_{2eq} kg^{-1}) had the highest amount of CO_{2eq} in the binary M + FP crop, and hemp seeds (417.0 kg CO_{2eq} ha^{-1}) in the single hemp crop. Seeds of faba bean (393.9 kg CO_{2eq} kg^{-1}) had the highest amount of CO_{2eq} in the binary (M + FB) crop, and the lowest (359.3 kg CO_{2eq} ha^{-1}) in the faba bean single crop compared to other crops.

The same amount of fertilizer was used, so the CO_{2eq} was the same in all tested cultivations. Higher fertilizer rates are associated with higher greenhouse gas emissions [64]. In the present study, we found that N fertilizer released the highest amount of 58.5 kg CO_{2eq} ha^{-1}, and K_2O fertilizer released the lowest amount of 6.85 kg CO_{2eq} kg^{-1}. In terms of GHG emissions of CO_{2eq} ha^{-1}, the best indicators were shown by the single faba bean crop. Faba beans also provide an ecological service due to their ability to biologically capture nitrogen [66].

The lowest total GHG emissions were calculated in single faba bean and single hemp crops (629.02 and 709.63 CO_{2eq} ha^{-1}) (Table 12). The highest ones were obtained from binary M + H and M + FB cultivations (1729.84 and 2067.33 CO_{2eq} ha^{-1}). Alimagham et al. [65] found that the total GHG emissions ranged from 1265.1 kg CO_{2eq} ha^{-1} to 2969.2 kg CO_{2eq} ha^{-1}. In the present experiment, the ternary cultivation, with the highest energy inputs, had an average CO_{2eq} of 1541.90 kg ha^{-1}.

4. Conclusions

The highest consumption of diesel fuel was found in a ternary crop (103.3 L ha^{-1}), 31–46% higher than in single cultivations and 22–35% higher than in binary cultivations because of double crop sowing and harvesting operations. For this reason, the energy input was the highest in the ternary crop or near twofold higher than in M, H, M + H crops, but similar to M + FB and H + FB. Despite this, the productivity of the ternary crop and, at the same time, the energy output were 2–5 times higher than in other treatments. This compensated for higher energy inputs and the energy efficiency ratio of ternary crop reaching 19.23. In the ternary crop, net energy was 1.9–5.3 times higher than in other tested cultivations.

The highest total GHG emissions were obtained in binary M + H and M + FB cultivations (1729.84 and 2067.33 CO_{2eq} ha^{-1}). As we expected, ternary cultivation with the highest energy inputs were responsible for average GHG emissions of 1541.90 kg ha^{-1} CO_{2eq}.

In general, this study showed that multi-cropping in agriculture can be an effective method for increasing high biomass production levels, to optimize the efficiency of energy consumption, while GHG emissions remain average. In order to make the cultivation of multi-crops even more efficient, it is necessary to improve sowing and harvesting systems so that ternary crops can be sown and harvested in one machine pass. In addition, faba beans should be included in ternary crops, as their biomass removes a significant part of the total biomass produced. It is advisable to specify the seeding rates of intercropped faba bean because faba bean seeding rates and seed energy equivalents are high and cause a slight disorder of energy input in agrotechnology.

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