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Article

Changes of Energy Balance and GHG Emissions in Legume Intercropped Maize Agroecosystem as a Result of Drought

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Abstract: Multi-cropping can solve the energy and GHG balance problems, but the emergence, development and productivity of such mixed crops are at risk due to increasing drought periods. For this reason, single maize crops with inter-row mellowing and weed-mulching practices were compared with faba bean, crimson and Persian clover, and alfalfa intercropped maize cultivations. Tests were performed at the Experimental Station of Vytautas Magnus University, Lithuania. Results showed that by the 30% higher energy inputs were calculated in technologies with intercropped crimson, Persian clover, and alfalfa than in monocropped maize. Single maize crops produced by the 23-40% higher biomass yields compare to clover and alfalfa intercropped maize because, due to the drought periods, intercrops weakly sprouted and developed. Lower harvests reduced the energy output by up to 38%, energy efficiency ratio - by up to 2.5 times and net energy - by up to 42%. All tested technologies were environmentally friendly and similar according to the CO₂ equivalent. Long-term drought periods during vegetative season due to climate change make us think about the improvement of intercropping technologies. Sowing intercrops at the same time with maize could solve the problem of its germination but highlight the problem of abundant weed spread. Therefore, this takes us to another sphere of agrotechnologies - the effective non-chemical weed control.

Keywords: *Zea mays* L.; legume intercrops; fuel; energy indices; CO₂eq; climate change

1. Introduction

Agriculture exerts the most significant influence on the environment among all human activities and is closely tied to changes in land use, energy consumption and greenhouse gas (GHG) emissions. Agriculture creates about 22% Lithuania's and up to 32% of global CO₂ emissions [1-3].

The most important factor in controlling GHG emissions are reduced use of organic fertilizers [4], tillage intensity and fertilization rates [5]. However conversely, in some no-till practices, there were found the significant increase in GHG emissions by 7.1% compared to conventional tillage [6]. Multi-cropping is also an effective example of the use of resources. This provides prerequisites for more efficient fuel and energy consumption, as well as a relatively lower CO₂ equivalent. Multi-cropping also initiates raise of soil fertility, phytosanitary conditions, protection against weeds, diseases, and pests. Successful increase in yield is also achieved with the help of multi-cropping [7-8], especially in the case of climate change, which frequently amplifying crop and yield losses [9].

It is important to choose the appropriate plants because the functions and benefits are performed differently. Clover, maize, faba bean, and alfalfa could serve as effective companions in multi-crops, given that maize has a high potential for biomass production [10]. Alfalfa and clovers provide distinctive advantages as a perennial crop, contributing to the development of organic matter for enhanced structure, stability, and water retention capacity. Incorporating clovers and alfalfa into a farm's rotation can enhance the yield of other crops and potentially decrease the requirement for

chemical inputs. It is notably recognized for its positive alfalfa impact on maize, which utilizes the nitrogen fixed in alfalfa's roots [11]. Faba beans are great plants for intercropping and ecological service [12]. However, multi-crops cultivation has still not been widely studied [13].

There is a lack of a standardized approach for determining greenhouse gas (GHG) emissions in crop production systems, and there remains a necessity to enhance the sustainability of agricultural technologies [14]. Estimating the total amount of carbon inputs in agrotechnologies poses challenges. It is beneficial to convert different inputs into equivalent carbon dioxide emissions for agricultural.

The main aim of this study was to evaluate the fuels, working time, inputs of energy for main materials and biomass energy outputs for production of differently biodiverse single and binary maize crops. We hypothesize that use of leguminous intercrops in maize cultivation will balance fuel and energy use, also stabilize the GHG emission.

2. Materials and Methods

2.1. Experimental Site

A stationary field experiment was started in 2022 at the Experimental station of Vytautas Magnus University, Agriculture Academy. Experimental soil was sandy loam (sand 57.4%, clay 14.9%) Planosol (Endohypogleyic-Eutric, *Ple-gln-w* [15]. The pH of the soil is 7.4–7.5, content of available phosphorus - 226–249, potassium - 102–121, magnesium - 560–791 mg kg⁻¹ and total nitrogen - 1.14–1.30 g kg⁻¹.

Lithuania is a country with surplus precipitation balance, but in nova days, 300–400 mm precipitation rates distributes not even with several drought periods during vegetative period (Table 1). In 2023 vegetative season, average air temperatures were similar as long-term average or higher but every second month of vegetative period was arid.

Table 1. Average air temperatures and precipitation rates. Kaunas Meteorological Station, April-October 2023.

Months	Average air temperatures °C		Precipitation rates mm	
	monthly	long-term	monthly	long-term
April	8.5	6.9	26.7	41.3
May	12.6	13.2	14.3	61.7
June	17.3	16.1	64.0	76.9
July	18.0	18.7	36.8	96.6
August	20.2	17.3	96.2	88.9
October	17.1	12.6	11.6	60.0

These conditions negatively influenced on the germination, development and productivity of legume intercrops, sowed after maize sprouting.

2.2. Treatments and Agronomic Practice

In 2023, maize (*Zea mays* L.) (hybrid P7034) was grown in the field experiment with intercrops of the *Fabaceae* family: faba bean (*Vicia faba* L.) (variety "Trumpet"), Crimson clover (*Trifolium incarnatum* L.) (variety - "Kardinal"), Persian clover (*Trifolium resupinatum* L.) (variety - "Rusty"), alfalfa (*Medicago sativa* L.) (variety - "Giulia"). Six treatments in total were performed:

1. Inter-row mellowing (control 1, K1);
2. Inter-row mulching with weeds – permaculture element (control 2, K2);
3. Intercropping and mulching with faba bean (LUP);
4. Intercropping and mulching with crimson clover (PUD);
5. Intercropping and mulching with Persian clover (PED);
6. Intercropping and mulching with blue-flowered alfalfa (MEL).

The field experiment was carried out in 4 replicates. The plots were arranged in a randomized manner. The *brutto* size of the plot was 18.4 m², the *netto* one was 18 m². In total, there were 24 plots in the experiment. The pre-crop was a black fallow.

In the fall, before the experiment was set up, the soil was ploughed with a Kverneland semi-screw plough. In the spring, when the soil reached physical maturity, it was cultivated with a compound cultivator KLG - 4.3–4 cm deep. On the same day, mineral fertilizers NPK 5:15:29 were distributed. Fertilizer rate was 300 kg ha⁻¹. After fertilizing, up to 3 days, the maize was sown with a Kverneland Accord Optima pneumo-mechanical seeding machine in 45 cm wide rows with a distance between seeds of 21 cm. After the maize germinated, the inter-rows were loosened and inter-row *Fabaceae* crops were inter-sown with a hand seeder for greenhouses, which sowed 4–6 rows. Maize and intercrops were sown according to the intended sowing rates (Table 2).

Table 2. Sowing rates (kg ha⁻¹) of differently intercropped maize cultivations.

Crop/Treatments	K1	K2	LUP	PUD	PED	MEL
Maize	30	30	30	30	30	30
Faba bean	-	-	200	-	-	-
Crimson clover	-	-	-	30	-	-
Persian clover	-	-	-	-	18	-
Alfalfa	-	-	-	-	-	20

The inter-rows of maize were mellowed, intercrops and weeds were cut and mulched 2–3 times during the maize growing season until the maize reaches a height of 50–70 cm.

The intercrops were cut with a hand brush cutter “Stihl” FS-550. Intercrops were started to be cut when they reach a height of 20–25 cm. The green mass of intercrops and weeds was spread in the inter-rows of maize. The inter-rows of Control 1 were mellowed manually.

Pesticides were not used in agro-technics. The biomass was harvested at the end of the maize vegetative period in October (after the grain has reached the beginning of hard maturity) manually. In the experiment, the energy of manual work was transformed into machine work (Table 3).

Table 3. Agro-technological operations.

Technological operation (machinery/depth/material rate)/Treatments	K1	K2	LUP	PUD	PED	MEL
Deep ploughing	o	o	o	o	o	o
Pre-sowing cultivation	o	o	o	o	o	o
Fertilization (N ₁₅ P ₄₅ K ₈₇ kg ha ⁻¹)	o	o	o	o	o	o
Maize sowing	o	o	o	o	o	o
Intercrops sowing	-	-	o	o	o	o
Inter-row loosening (2–3 cm depth)	ooo	o	o	o	o	o
Intercrops mulching	-	oo	oo	oo	oo	oo
Low harvester load biomass harvesting	o	o	o	-	-	-
High harvester load biomass harvesting	-	o	-	o	-	o

Notes: K1 - inter-row mellowing (control 1); K2 - inter-row mulching with weeds - permaculture element (control 2); LUP - intercropping and mulching with faba bean; PUD - intercropping and mulching with crimson clover; PED - intercropping and mulching with Persian clover; MEL - intercropping and mulching with alfalfa. A dash means that no operation was performed, and a tick indicates the number of operations performed.

In the calculations of the energy and environmental assessment of agrotechnologies, we used the normative data of the agricultural machinery of the Lithuanian Institute of Economy and Rural Development [16-17]. We used a field area of 2–10 ha for the calculations. The power of tractors varied

from 45 to 102 kW, biomass harvester - 250 kW. The data of tractor-operated drills are presented in calculations when up to 200 kg ha⁻¹ seeds were sown.

For cutting the inter-rows, we chose the closest available mounted rotary mower. In the case of a plot up to 10 ha in area, biomass yield up to 12 t ha⁻¹, and a swath width of 3 m, a 6-furrow biomass harvester was chosen. We modelled that the K1 and K2 plots, where no intercrops were grown, would have a lower harvester load than in intercropped maize. A lower load was placed on the combine harvester also in maize with faba beans, because there are practically no faba beans in the inter-rows before harvest.

In Table 4, we presented the main technical indicators of the technological processes, including machine power, working width, output rate and working time costs, and diesel fuel costs. The highest fuel consumption is determined for harvesting operations. Under higher load conditions, fuel consumption will reach as much as 27.6 L ha⁻¹.

Table 4. Technical indicators of technological operations.

Technological operation	Machinery power (kW)	Working width (m)	Field capacity (ha h ⁻¹)	Working time (h ha ⁻¹)	Fuel consumption (L ha ⁻¹)
Deep ploughing	102	1.75	0.80	1.25	24.1
Pre-sowing cultivation	102	7.00	4.56	0.22	6.4
Maize sowing	45	3.00	1.41	0.71	4.0
Intercrops sowing	67	3.00	1.31	0.76	9.8
Fertilization	67	14.00	16.55	0.06	0.6
Inter-row loosening	54	3.00	1.56	0.64	4.1
Intercrops mulching	54	3.00	2.05	0.49	5.3
Low harvester load biomass harvesting	250	3.00	1.82	0.55	19.2
High harvester load biomass harvesting	250	3.00	1.37	0.73	27.6

2.3. Methodology

Samples for maize and intercrops biomass productivity evaluation were taken in at least in 5 spots per each experimental plot and for each species of crop. 48 samples were formed totally. Biomass was dried at a temperature of 105 °C to absolutely dry form. The results of dried biomasses are presented in this study.

By selecting the energy equivalents of technological operations (Table 5), it is possible to evaluate the energy efficiency of different agro-technologies. The seed rates used for the calculations, indicated in Table 2, were fertilized at the rate of N₁₅P₄₅K₈₇ kg ha⁻¹ in all experimental plots.

Table 5. Energy equivalents in agro-technologies.

Indices	Energy equivalent	Reference
Inputs:		
Human labour (MJ h ⁻¹)	1.96	[18]
Diesel fuel (MJ L ⁻¹)	56.3	[18]
Agricultural machinery (MJ h ⁻¹)	357.2	[19]
Seeds of maize (MJ kg ⁻¹)	16.6	[18]
Seeds of faba bean (MJ kg ⁻¹)	21.0	[20]
Seeds of clover	11.0	[21]
Seeds of alfalfa	11.9	[22]
N (MJ kg ⁻¹)	60.6	[18]
P ₂ O ₅ (MJ kg ⁻¹)	11.1	[18]
K ₂ O (MJ kg ⁻¹)	6.7	[18]

Outputs:

Maize biomass (MJ kg ⁻¹ dry matter)	17.7	[23]
Faba bean biomass (MJ kg ⁻¹ dry matter)	17.0	[24]
Clover biomass (MJ kg ⁻¹ dry matter)	11.6	[25]
Alfalfa biomass (MJ kg ⁻¹ dry matter)	11.0	[25]

It is convenient to evaluate agro-technologies according to the relative emissions of greenhouse gases. The equivalent of CO₂ gas (CO_{2eq}) is used for this (Table 6).

Table 6. CO₂ equivalents in agro-technologies.

Inputs	CO ₂ equivalent	Reference
Diesel fuel (kg CO _{2eq} L ⁻¹)	2.76	[26]
Agricultural machinery (kg CO _{2eq} MJ ⁻¹)	0.071	[27]
Seeds of maize (kg CO _{2eq} kg ⁻¹)	15.3	[28]
Seeds of legumes (kg CO _{2eq} kg ⁻¹)	0.22	[29]
N (kg CO _{2eq} kg ⁻¹)	1.30	[1]
P ₂ O ₅ (kg CO _{2eq} kg ⁻¹)	0.20	[1]
K ₂ O (kg CO _{2eq} kg ⁻¹)	0.15	[1]

A computer program ANOVA from the statistical software SELEKCIJA (vers. 5.00, author dr. Pavelas Tarakanovas, Lithuanian Institute of Agriculture, Akademija, Kedainiu distr., Lithuania) was used for the data analysis. 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 a necessary factor in agriculture [30], because agro-technologies use plenty different powerful machines for seeding, soil tillage, harvesting and crop care [31-32] and other scientists found that the largest part of energy inputs was used in fertilizing chemical fertilizers. The lowest energy input was human labor [33].

In our experiment, energy consumption for human labor increased from 14.1% to 22.1% when growing intercrops compared to the control treatments (Table 7). Fuel consumption also increased from 13.9% to 30.9% in all intercropped cultivations. With the use of agricultural machinery, the same trends emerged as in the previously mentioned analyzed indicators.

Table 7. Energy inputs of technological operations and materials in crop biomass production systems, MJ ha⁻¹.

Inputs	K1	K2	LUP	PUD	PED	MEL
Human labor	9.2	8.6	10.5	10.5	10.5	10.5
Diesel fuel	3749.6	3896.0	4436.4	4909.4	4909.4	4909.4
Agricultural machinery	1682.4	1575.2	1911.0	1911.2	1911.2	1911.0
Seed of maize (30 kg ha ⁻¹)	498.0	498.0	498.0	498.0	498.0	498.0
Seed of faba bean (200 kg ha ⁻¹)	-	-	4200.0	-	-	-
Seed of clover (30 and 18 kg ha ⁻¹)	-	-	-	330.0	198.0	-
Seed alfalfa (20 kg ha ⁻¹)	-	-	-	-	-	238.0
N	909.0	909.0	909.0	909.0	909.0	909.0
P ₂ O ₅	499.5	499.5	499.5	499.5	499.5	499.5
K ₂ O	582.9	582.9	582.9	582.9	582.9	582.9
Total energy input	6438.7	6477.3	8347.8	9650.5	9518.5	9558.3

Notes: K1 - inter-row mellowing (control 1); K2 - inter-row mulching with weeds - permaculture element (control 2); LUP - intercropping and mulching with faba bean (LUP); PUD - intercropping and mulching with crimson

clover (PUD); PED - intercropping and mulching with Persian clover (PED); MEL - intercropping and mulching with alfalfa.

The lowest total energy consumption was calculated by the agrotechnologies applied in the control plots K1 and K2.

3.2. Crop productivity and energy indices

Energy is an important driving force of development, but it is particularly important in the agricultural sector, as agriculture is not only a consumer of energy, but also a producer [30], because maize and hemp biomass is the beneficial resource for biofuel production [34-36].

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 8.

Table 8. Productivity and energy indices of different single- and binary- maize cultivations.

Treat- ments	Harvest kg ha ⁻¹ of dried biomass			Energy input MJ ha ⁻¹	Energy output MJ ha ⁻¹	Energy efficiency ratio	Net energy MJ ha ⁻¹
	Maize	Intercrop	Total				
K1	21800.0	-	21800.0	6438.7	385860.0	59.9	379421.3
K2	20500.0	-	20500.0	6477.6	362850.0	56.0	356372.7
LUP	17600.0	4268*	21868.0	8347.8	384008.0	46.0	375660.2
PUD	16600.0	569	17169.0	9650.5	300420.0	31.1	290769.5
PED	16100.0	561	16661.0	9518.5	291478.0	30.6	281959.5
MEL	12900.0	275	13175.0	9558.3	231355.0	24.2	221796.7

Notes: K1 - inter-row mellowing (control 1); K2 - inter-row mulching with weeds - permaculture element (control 2); LUP - intercropping and mulching with faba bean (LUP); PUD - intercropping and mulching with crimson clover (PUD); PED - intercropping and mulching with Persian clover (PED); MEL - intercropping and mulching with alfalfa. * - theoretical number based on Romaneckas et al. [37]. In our experiment, the faba beans were cut and mulched because due to poor germination and development, the inter-rows were mainly covered with weeds.

In agrotechnologies, energy input is the energy value of the harvest. The most energy was accumulated with the harvest in the plots of the first three treatments (Table 8). When clover and alfalfa were intercropped, they competed with maize and their yields decreased. In the year of average humidity, the intercrops produce a significant biomass yield, but in the drought conditions in 2023, their yield reached only 300-500 kg ha⁻¹ and contributed little to energy reserves. Therefore, the largest energy output, the energy consumption ratio and the net energy are calculated in control plots without intercrops. In the absence of moisture, intercrops germinate poorly and develop slowly, so various methods of sowing, fertilizing, selecting plant species or varieties, as suggested by some authors [38-39], bring little benefit.

3.3. Environmental impact

A large proportion of anthropogenic emissions come from industrial processes, but agriculture is considered one of the most polluting sectors in the world [40-41]. Agriculture is a major source of greenhouse gases (GHG) [Hoffman et al., 2018]. Considering that climate change is caused by the increasing emission of greenhouse gases due to anthropogenic effects [42], sustainable farming ensures lower emissions to the environment and the entire food chain [43-44].

The GHG emissions for the agro-technological inputs were recalculated into a CO_{2eq} system using the conversion equivalents (Table 9).

Table 9. GHG emissions from a single- and binary- maize cultivation.

Indices/Treatments	K1	K2	LUP	PUD	PED	MEL
Diesel fuel (kg CO _{2eq} ha ⁻¹)	183.8	191.0	217.5	240.7	240.7	240.7
Agricultural machinery (kg CO _{2eq} ha ⁻¹)	119.4	111.8	135.7	135.7	135.7	135.7
Seed (kg CO _{2eq} ha ⁻¹)	459.0	459.0	503.0	465.6	463.0	463.4
Fertilizer (kg CO _{2eq} ha ⁻¹)	41.6	41.6	41.6	41.6	41.6	41.6
Total GHG emission (kg CO _{2eq} ha ⁻¹)	803.8	803.4	897.8	883.6	881.0	881.4

Notes: K1 - inter-row mellowing (control 1); K2 - inter-row mulching with weeds - permaculture element (control 2); LUP - intercropping and mulching with faba bean (LUP); PUD - intercropping and mulching with crimson clover (PUD); PED - intercropping and mulching with Persian clover (PED); MEL - intercropping and mulching with alfalfa.

Total GHG emissions were the highest in intercropped maize cultivations, when assessing fuel (from 13.9% to 31.0%), agricultural machinery (from 13.7% to 21.4%), and sowing work (from 0.9% to 9.6%) compared to the controls K1 and K2, because no agricultural machinery, fuel and labor hours were used for intercrop sowing. In our experiment, GHG emissions varied from 803.8 to 897.8 kg CO_{2eq} ha⁻¹ and were similar for all technologies. The level of GHG emissions was low because Juarez-Hernandez et al., [2019] found that the total GHG emissions ranged from 152.9 kg CO_{2eq} ha⁻¹ to 3475.8 kg CO_{2eq} ha⁻¹ in maize cultivation.

4. Conclusions

The highest energy inputs were calculated in technologies with intercropped crimson, Persian clover, and alfalfa or about 30% higher than in monocropped maize. Maize crops produced higher biomass yields without competing with intercrops. Contrary to expectations, the drought caused clover and alfalfa intercrops biomass losses by the 23-40% compare with monocropped maize cultivations. Lower harvests reduced the energy output by up to 38%, energy efficiency ratio - by up to 2.5 times and net energy - by up to 42%.

According to the CO₂ equivalent, all tested technologies environmentally friendly and were similar - differed by about 10%.

We expected that, although intercrops would compete with maize and reduce its productivity, it would produce abundant biomass to compensate for the losses. Due to the drought, intercrops sprouted and developed slowly, and their biomass was low, so the energy input of technology with intercrops was lower than that of monocropped maize. This has thrown energy efficiency and net energy out of balance. Due to climate change, the increased number of drought periods make us think about the improvement of intercrops sowing technologies. Sowing intercrops at the same time with maize could solve the problem of its germination, but there would be a problem of abundant weeds. Therefore, it is necessary to study in more detail what will be the effect of the spread weeds on the intercropped maize agroecosystem and its energy and GHG balance.

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References

1. Lal, R. Carbon emission from farm operations. *Environ. Int.* **2004**, *30*(7), 981–990.
2. Failla, S.; Ingraio, C.; Arcidiacono, C. Energy consumption of rainfed durum wheat cultivation in a Mediterranean area using three different soil management systems. *Energy* **2020**, *195*, 1–13.
3. Saldukaitė, L.; Šarauskis, E.; Zabrodskiy, A.; Adamavičienė, A.; Buragienė, S.; Kriauciūnienė, Z.; Savickas, D. Assessment of energy saving and GHG reduction of winter oilseed rape production using sustainable strip tillage and direct sowing in three tillage technologies. *Sustain. Energy Technol. Assess.* **2022**, *51*, 101911.
4. Bručienė, I.; Aleliūnas, D.; Šarauskis, E.; Romanekas, K. Influence of Mechanical and Intelligent Robotic Weed Control Methods on Energy Efficiency and Environment in Organic Sugar Beet Production. *Agric.* **2021**, *11*, 449.
5. Haddaway, N.R.; Hedlund, K.; Jackson, L.E.; Kätterer, T.; Lugato, E.; Thomsen, I.K.; Jørgensen, H.B.; Isberg, P.E. How does tillage intensity affect soil organic carbon? *A systematic review. Environ. Evid.* **2017**, *6*, 30.
6. Huang, Y.; Ren, W.; Wang, L.; Hui, D.; Grove, J. H.; Yang, X.; Tao, B.; Goff, B. Greenhouse gas emissions and crop yield in no-tillage systems: a meta-analysis. *Agric. Ecosyst. Environ.* **2018**, *268*, 144–153.
7. Haberl, H.; Erb, K.H.; Krausmann, F.; Bondeau, A.; Lauk, C.; Muler, C.; Plutzer, C.; Steinberger, J.K. Global bioenergy potentials from agricultural land in 2050: Sensitivity to climate change, diets and yields. *Biomass bioenergy* **2011**, *35*(12), 4753–4769.
8. Blanco-Canqui, H.; Ruis, S. J. Cover crop impacts on soil physical properties: *A review. SSSAJ.* **2020**, *84*, 1527–1576.
9. De Cárcer, P. S.; Sinaj, S.; Santonja, M.; Fossati, D.; Jeangros, B. Long-term effects of crop succession, soil tillage and climate on wheat yield and soil properties. *Soil Tillage Res.* **2019**, *190*, 209–219.
10. Abukhadra, M.R.; Adlii, A.; Jumah, M.N.B.; Othman, S.; Alruhaimi, R.S.; Salama, Y.F.; Allam, A.A. Sustainable conversion of waste corn oil into biofuel over different forms of synthetic muscovite-based K⁺/Na⁺ sodalite as basic catalysts; characterization and mechanism. *MRX.* **2021**, *6*, 1–13.
11. Fernandez, A. L.; Sheaffer, C. C.; Tautges, N. E.; Putnam, D. H.; Hunter, M. C. Alfalfa, wildlife, and the environment. *NAFA* **2019**, 3–4.
12. Romanekas, K.; Balandaitė, J.; Sinkevičienė, A.; Kimbirauskienė, R.; Jasinskas, A.; Ginelevičius, U.; Romanekas, A.; Petlickaitė, R. Short-Term Impact of Multi-Cropping on Some Soil Physical Properties and Respiration. *Agron.* **2022**, *12*, 2–17.
13. Francis, C.A. Porter, P. Multicropping. *Crop Syst.* **2016**, *3*, 29–33.
14. Trimpler, K.; Stockfisch, N.; Märlander, B. The relevance of N fertilization for the amount of total greenhouse gas emissions in sugar beet cultivation. *Eur. J. Agron.* **2016**, *81*, 64–71.
15. FAO. IUSS working group WRB. World Reference Base for Soil Resources, 3rd ed.; World Soil Resources Reports No.106. Rome, Italy, **2014**. Available online: <http://www.fao.org/3/i3794en/I3794en.pdf> (accessed on 14 December 2023).
16. Pagrindinio žemės dirbimo darbai/Primary tillage works. In *Mechanizuotų žemės ūkio paslaugų įkainiai. Rates for mechanized agricultural services*; Srebutėnienė, I., Eds.; Lietuvos agrarinės ekonomikos institutas: Vilnius, Lithuania, **2017**. Available online: https://zum.lrv.lt/uploads/zum/documents/files/IKAINIAI_2017_I_dalis.pdf (accessed on 2023 August 2023) (in Lithuanian).
17. Pasėlių priežiūra ir šienapjūtės darbai/Crop care and mowing work. In *Mechanizuotų žemės ūkio paslaugų įkainiai. Rates for mechanized agricultural services*; Srebutėnienė, I.; Stalgienė, A., Eds.; Lietuvos agrarinės ekonomikos institutas: Vilnius, Lithuania, **2017** (in Lithuanian).
18. Lal, B.; Gautam, P.; Nayak, A.K.; Panda, B.B.; Bihari, P.; Tripathi, R.; Shahid, M.; Guru, P.K.; Chatterjee, D.; Kumar, U.; Meena, B.P. Energy and carbon budgeting of tillage for environmentally clean and resilient soil health of rice-maize cropping system. *J. Clean. Prod.* **2019**, *226*(8), 15–30.
19. Campiglia, E.; Gobbi, L.; Marucci, A.; Rapa, M.; Ruggieri, R.; Vinci, G. Hemp Seed Production: Environmental Impacts of Cannabis sativa L. Agronomic Practices by Life Cycle Assessment (LCA) and Carbon Footprint Methodologies. *Sustainability* **2020**, *12*, 65–70.
20. Kazemi, H.; Shahbyki, M.; Baghbani, S. Energy analysis for faba bean production: a case study in Golestan province, Iran. *Sustain. Prod. Cons.* **2015**, *3*, 15–20.
21. Red clover. Available online: <https://www.mountsinai.org/health-library/herb/redclover#:~:text=Red%20clover%20is%20a%20source,are%20found%20in%20many%20plants> (accessed on 05 02 2024)
22. Ekologiškos liucernos sėklos / Organic alfalfa seeds. Available online: <https://www.vyp.lt/produktas/ekologiskos-liucernos-seklos/> (accessed on 05 02 2024)
23. Amir, S. Hemp as a biomass crop. Technical Article, April 2023. Available online: <https://www.biomassconnect.org/wp-content/uploads/2023/04/Hemp-as-Biomass-Crop.pdf> (accessed on 21 August 2023).
24. Jasinskas, A.; Minajeva, A.; Šarauskis, E.; Romanekas, K.; Kimbirauskienė, R.; Pedišius, N. Recycling and utilisation of faba bean harvesting and threshing waste for bioenergy. *Renew. Energ.* **2020**, *162*, 257–266.

25. Brown, H.; Moot, D. 2004. Quality and quantity of chicory, lucerne and red clover production under irrigation. New Zealand Grassland Association.
26. Moghimi, M.R.; Pooya, M.; Mohammadi, A. Study on energy balance, energy forms and greenhouse gas emission for wheat production in Gorve city, Kordestan province of Iran *Eur. J. Exp. Biol.* **2014**, *4*(3), 234–239.
27. Pishgar-Komleh, S.H.; Ghahderijani, M.; Sefeepari, P. Energy consumption and CO₂ emissions analysis of potato production based on different farm size levels in Iran. *J. Clean. Prod.* **2012**, *33*, 183–191.
28. Singh, S.; Mittal, J.P.; Verma, S.R. Energy requirements for production of major crops in India. *Agric. Mech. Asia Africa Latin. Am.* 1997, *28*(4), 13–17.
29. Tidaker, P.; Karlsson Potter, H.; Carlsoon, G.; Roos, E. 2021. Towards sustainable consumption of legumes: How origin, processing and transport affect the environmental impact of pulses. *Sustain. Prod. Consum.* **2021**, *27*, 496–508.
30. Imran, M.; Özçatalba, S.O.; Bashir, M.K. Estimation of energy efficiency and greenhouse gas emission of cotton crop in South Punjab, Pakistan. *J. Saudi Soc. Agric. Sci.* **2020**, *19*, 216–224.
31. Šarauski, E.; Romanekas, K.; Jasinskas, A.; Kimbirauskienė, R.; Naujokienė, V. Improving energy efficiency and environmental mitigation through tillage management in faba bean production. *Energy* **2020**, *209*, 118453.
32. Mohammadshirazi, A.; Akram, A.; Rafiee, S.; Avval, S.H.M., Kalhor, E.B. An analysis of energy use and relation between energy inputs and yield in tangerine production. *Renew. sustain. energy rev.* **2012**, *16*(7), 4515–4521.
33. Gezer, I.; Acaroglu, M.; Haciseferogullari, H. Use of energy and labour in apricot agriculture in Turkey. *Biomass Bioenergy.* **2003**, *24*, 215–219.
34. Prade, T.; Svensson, S.E.; Andersson, A.; Mattsson, J.E. Biomass and energy yield of industrial hemp for biogas and solid fuel. *Biomass & Bioenergy.* **2011**, *35*(7), 3040–3049.
35. Prade, T.; Svensson, S.E.; Mattsson, J.E. Energy balances for biogas and solid biofuel production from industrial hemp. *Biomass & Bioenergy.* **2012**, *40*(7), 36–52.
36. Torney, F.; Moeller, L.; Scarpa, A.; Wang, K. Genetic engineering approaches to improve bioethanol production from maize. *Curr. Opin. Biotechnol.* **2007**, *18*(3), 193–199.
37. Romanekas, K.; Švereikaitė, A.; Kimbirauskienė, R.; Sinkevičienė, A.; Balandaitė, J. The Energy and Environmental Evaluation of Maize, Hemp and Faba Bean Multi-Crops. *Agronomy* **2023**, *13*, 2316. <https://doi.org/10.3390/agronomy13092316>
38. Agegnehu, G. Yield potential and land-use efficiency of wheat and faba bean mixed intercropping. *Agron. Sustain. Dev.* **2008**, *28*, 257–263.
39. Francis C. A.; Porter P. Multicroping. *Encyclopedia of App. Plant Sci.* (Second Edition). **2017**, *3*, 29–33.
40. Hoffman, E.; Cavigelli, M.A.; Camargo, G.; Ryan, M.; Ackroyd, V.J.; Richard, T.L.; Mirsky, S. Energy use and greenhouse gas emissions in organic and conventional grain crop production: Accounting for nutrient inflows. *Agric. Syst.* **2018**, *162*, 89–96.
41. Šarauski, E.; Masilionytė, L.; Juknevičius, D.; Buragienė, S.; Kriauciūnienė, Z. Energy use efficiency, GHG emissions, and cost-effectiveness of organic and sustainable fertilisation. *Energy*, **2019**, *172*, 1151–1160.
42. Gant, Y.; Liang, C.; Hamel, C.; Cutforth, H.; Wang, H. Strategies for reducing the carbon footprint of field crops for semiarid areas. *A review. Agron. Sustain. Dev.* **2011**, *31*, 643–656.
43. Whitfield, J. Agriculture and environment: How green was my subsidy? *Nature*, **2006**, *439*(7079), 908–910.
44. O'Donoghue, C.; Chyzheuskaya, A.; Grealis, E.; Kilcline, K.; Finnegan, W.; Goggins, J.; Hynes, S.; Ryan, M. Measuring GHG emissions across the agri-food sector value chain: the development of a bioeconomy input-output model. *Int. J. Food Syst. Dyn.* 2019, *10*(1), 55–85.
45. Juarez-Hernandez, S.; Uson, S.; Pardo, C.S. Assessing maize production systems in Mexico from an energy, exergy, and greenhouse-gas emissions perspective. *Energy.* **2019**, *170*, 199–211.

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