Article

Not peer-reviewed version

Differences of Energy Balance and GHG Emissions in Legume Intercropped Maize Agroecosystem as a Result of Climate Change

Kęstutis Romaneckas * , Austėja Švereikaitė , Rasa Kimbirauskienė , Aušra Sinkevičienė , Aida Adamavičienė , Algirdas Jasinskas

Posted Date: 21 June 2024

doi: 10.20944/preprints202406.1429.v1

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

Article

Differences of Energy Balance and GHG Emissions in Legume Intercropped Maize Agroecosystem as a Result of Climate Change

Kęstutis Romaneckas *, Austėja Švereikaitė, Rasa Kimbirauskienė, Aušra Sinkevičienė, Aida Adamavičienė and Algirdas Jasinskas

Agriculture Academy, Vytautas Magnus University, Studentu Str. 11, Akademija LT-53361, Kaunas distr., Lithuania; jovita.balandaite@vdu.lt (J.B.); austeja.svereikaite@vdu.lt (A.Š.); rasa.kimbirauskiene@vdu.lt (R.K.); ausra.sinkeviciene@vdu.lt (A.S.); aida.adamaviciene@vdu.lt (AA); algirdas.jasinskas@vdu.lt (A.J.)

* Correspondence: kestutis.romaneckas@vdu.lt (K.R.); Tel.: +370-656-300-44

Abstract: Multicropping can solve the energy and GHG balance problems, but the emergence, development and productivity of such mixed crops are at risk due to uneven distribution of precipitation. For this reason, investigations were performed at the Experimental Station of Vytautas Magnus University, Lithuania. Single maize crop was compared with Crimson/red clover, Persian clover, and alfalfa intercropped maize cultivations. Results showed that under arid conditions, the intercrops biomass was about 4 times less than under humid. Humid conditions were less suitable for maize and when growing with intercrops they produced about 3-5 t ha^{-1} less dried biomass, and when growing sole - about 6 t ha^{-1} less biomass than in arid conditions. Due to the higher yield of maize biomass in arid season, better energy indicators of the crop were obtained in arid conditions than in humid. The difference between net energy was about 122-123 MJ ha^{-1} in all treatments, except for the maize crop with intercropped alfalfa, where the difference was 62 MJ ha^{-1}. All tested technologies were environmentally friendly, CO_2 equivalent varied between treatments from 804 to 884 kg ha^{-1}. Uneven distribution of precipitation during vegetative season makes us think about the improvement of intercropping technologies. Sowing intercrops at the same time with maize could improve its germination but increase the problem of weed spread.

Keywords: *Zea mays* L.; legume intercrops; fuel; energy indices; CO_2eq; 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 CO_2 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 CO_2 equivalent. Multi-cropping also initiates a rise 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 amplifies 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 in humid and arid vegetative conditions. We hypothesize that use of leguminous intercrops in maize cultivation will balance fuel and energy use, also stabilize the GHG emission.

2. Results and Discussion

2.1. Energy Inputs

Energy consumption is a necessary factor in agriculture [15], because agrotechnologies use plenty different powerful machines for seeding, soil tillage, harvesting and crop care [16,17] and other scientists found that the largest part of energy inputs was used in fertilizing chemical fertilizers. The lowest energy input was human labor [18].

In our experiments, energy consumption for human labor increased about 14% when growing intercrops compared to the control treatment (Table 1). Fuel consumption also increased up to 14% in all intercropped cultivations. With the use of agricultural machinery, the same trends emerged as in the previously mentioned analyzed indicators.

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

Inputs	CO	RC	PC	AA
Human labor	9.2	10.5	10.5	10.5
Diesel fuel	3749.6	4909.4	4909.4	4909.4
Agricultural machinery	1682.4	1911.2	1911.2	1911.0
Seed of maize (30 kg ha^{-1})	498.0	498.0	498.0	498.0
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
P_2O_5	499.5	499.5	499.5	499.5
K_2O	582.9	582.9	582.9	582.9
Total energy input	7930.6	9650.5	9518.5	9558.3

Notes: CO - inter-row mellowing (control treatment); RC - intercropping and mulching with Crimson/red clover; PC - intercropping and mulching with Persian clover; AA - intercropping and mulching with alfalfa.

The lowest total energy consumption was calculated by the agrotechnology without intercrops (CO).

2.2. 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 [15], because maize and hemp biomass are the beneficial resource for biofuel production [19,21].

In our study, the highest yield of dried biomass was received in single maize crops without companions (Table 2). The difference in biomass yields between vegetation conditions showed that maize makes excellent use of even lower rainfall amounts, and excess rainfall is harmful. However,

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 21 June 2024 doi:10.20944/preprints202406.1429.v1

in arid years, intercrops are more affected and cope poorly with soil conservation tasks (data are not presented).

Table 2. Harvest of single and binary maize cultivations in different vegetative conditions, kg ha^{-1} of dried biomass

Treatment	Humid vegetative season			Arid vegetative season		
	Maize	Intercrop	Total	Maize	Intercrop	Total
CO	14,920	-	14,920	21,800	-	21,800
RC	10,090	2,722	12,812	16,600	569	17,169
PC	9,790	2,134	11,924	16,100	561	16,661
AA	9,780	1,206	10,986	12,900	275	13,175

Notes: CO - inter-row mellowing (control treatment); RC - intercropping and mulching with Crimson/red clover; PC - intercropping and mulching with Persian clover; AA - intercropping and mulching with alfalfa.

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 3. In agrotechnologies, energy output is the energy value of the harvest. 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 [22,23], bring little benefit.

Table 3. Energy indices of single and binary maize cultivations in different vegetative conditions

Treat-ments	Energy input MJ ha^{-1}		Energy output MJ ha^{-1}		Energy efficiency ratio		Net energy MJ ha^{-1}	
	HS	AS	HS	AS	HS	AS	HS	AS
CO	6,439		264,084	385,860	41.0	59.9	257,645	379,421
RC	9,650		178,593	300,420	18.5	31.1	168,943	290,769
PC	9,518		168,478	291,478	17.7	30.6	158,960	281,959
AA	9,558		169,182	231,355	17.7	24.2	159,624	221,797

Notes: CO - inter-row mellowing (control treatment); RC - intercropping and mulching with Crimson/red clover; PC - intercropping and mulching with Persian clover; AA - intercropping and mulching with alfalfa. HS – humid vegetative season, AS – arid vegetative season.

2.3. 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. Agriculture is a major source of greenhouse gases (GHG) [24,25]. Considering that climate change is caused by the increasing emission of greenhouse gases due to anthropogenic effects [26], sustainable farming ensures lower emissions to the environment and the entire food chain [27,28].

The GHG emissions for the agrotechnological inputs were recalculated into a CO_{2eq} system using the conversion equivalents (Table 4).

Table 4. GHG emissions from a single and binary maize cultivation

Indices/Treatments	CO	RD	PC	AA
Diesel fuel (kg CO_{2eq} ha^{-1})	183.8	240.7	240.7	240.7
Agricultural machinery (kg CO_{2eq} ha^{-1})	119.4	135.7	135.7	135.7
Seed (kg CO_{2eq} ha^{-1})	459.0	465.6	463.0	463.4
Fertilizer (kg CO_{2eq} ha^{-1})	41.6	41.6	41.6	41.6
Total GHG emission (kg CO_{2eq} ha^{-1})	803.8	883.6	881.0	881.4

Notes: CO - inter-row mellowing (control treatment); RC - intercropping and mulching with Crimson/red clover; PC - intercropping and mulching with Persian clover; AA - 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. Juarez-Hernandez et al. [29] found that the total GHG emissions in tested maize agrotechnologies ranged from 152.9 kg CO_{2eq} ha^{-1} to 3475.8 kg CO_{2eq} ha^{-1}.

3. Materials and Methods

3.1. Experimental Site

Stationary field experiments on maize intercropping were performed in 2009-2011 and the newest one 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* [30]. The pH of the soil is 7.1—7.5, content of P_2O_5- 130—249, K_2O - 74—121, MgO - 560—791 mg kg^{-1} and N_{tot} — 1.14—1.30 g kg^{-1}. Data from 2010 (humid vegetative season) and 2023 (arid vegetative season) were analyzed.

Lithuania is a country with surplus precipitation balance, but in nova days, 300–400 mm precipitation rates distribute not even with several drought periods during vegetative period (Table 5). Meteorological data of 2010 show that the weather during the maize growing season was warm and more humid than usual. The precipitation rate ranged 557 mm. Warm and humid summers are good for maize, but the rainfall was too much. Water often stagnated in the rows, soil aeration and nutritional conditions worsened. In 2023 vegetative season, average air temperatures were similar as long-term average or higher, but vegetative period was arid with 250 mm of precipitations only.

Table 5. Average air temperatures and precipitation rates. Kaunas Meteorological Station, April-October 2010 and 2023.

Months	Average air temperatures °C		Precipitation rates mm	
	monthly	long-term	monthly	long-term
April	7.4/8.5	6.9	58.5/26.7	41.3
May	13.7/12.6	13.2	94.8/14.3	61.7
June	16.5/17.3	16.1	127.0/64.0	76.9
July	21.9/18.0	18.7	100.7/36.8	96.6
August	19.7/20.2	17.3	112.5/96.2	88.9
October	12.0/17.1	12.6	63.3/11.6	60.0

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

3.2. Treatments and Agronomic Practice

In our study, following treatments were evaluated:
1. Inter-row mellowing (CO);
2. Intercropping and mulching with Crimson/red clover (RD);
3. Intercropping and mulching with Persian clover (PC);
4. Intercropping and mulching with alfalfa (AA).

The field experiment was carried out in 4 replicates. Crops were grown as continued cultivation.

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. The fertilizer rate was 300 kg ha^{-1}. After fertilizing, up to 3 days, the maize was sown

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 21 June 2024 doi:10.20944/preprints202406.1429.v1

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 6).

Table 6. Sowing rates (kg ha^{-1}) of differently intercropped maize cultivations.

Crop/Treatment	CO	RD	PC	AA
Maize	30	30	30	30
Crimson/red 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 distributed in the inter-rows of maize. The inter-rows of Control 1 were mellowed manually.

Pesticides were not used in agrotechnologies. 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 7).

Table 7. Agrotechnological operations

Technological operation (machinery/depth/material rate)/Treatments	CO	RD	PC	AA
Deep ploughing	o	o	o	o
Pre-sowing cultivation	o	o	o	o
Fertilization (N_{15} P_{45} K_{87} kg ha^{-1})	o	o	o	o
Maize sowing	o	o	o	o
Intercrops sowing	-	o	o	o
Inter-row loosening (2–3 cm depth)	ooo	o	o	o
Intercrops mulching	-	oo	oo	oo
Low harvester load biomass harvesting	o	-	-	-
High harvester load biomass harvesting	-	o	o	o

Notes: K1 - inter-row mellowing (control 1); RC - intercropping and mulching with Crimson/red clover; PC - intercropping and mulching with Persian clover; AA - 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 [31,32]. 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 CO plots, where no intercrops were grown, would have a lower harvester load than in intercropped maize.

In Table 8, 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 8. 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

3.3. Methodology

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

By selecting the energy equivalents of technological operations (Table 9), it is possible to evaluate the energy efficiency of different agrotechnologies. The seed rates used for the calculations, indicated in Table 2, were fertilized at the rate of $N_{15}P_{45}K_{87}$ kg ha^{-1} in all experimental plots.

Table 9. Energy equivalents in agrotechnologies

Indices	Energy equivalent	Reference
Inputs:		
Human labor (MJ h^{-1})	1.96	[33]
Diesel fuel (MJ L^{-1})	56.3	[33]
Agricultural machinery (MJ h^{-1})	357.2	[34]
Seeds of maize (MJ kg^{-1})	16.6	[33]
Seeds of clover	11.0	[35]
Seeds of alfalfa	11.9	[36]
N (MJ kg^{-1})	60.6	[33]
P_2O_5 (MJ kg^{-1})	11.1	[33]
K_2O (MJ kg^{-1})	6.7	[33]
Outputs:		
Maize biomass (MJ kg^{-1} dry matter)	17.7	[37]
Clover biomass (MJ kg^{-1} dry matter)	11.6	[38]
Alfalfa biomass (MJ kg^{-1} dry matter)	11.0	[38]

It is convenient to evaluate agrotechnologies according to the relative emissions of greenhouse gases. The equivalent of CO_2 gas (CO_{2eq}) is used for this (Table 10).

Table 10. CO_2 equivalents in agrotechnologies

Inputs	CO_2 equivalent	Reference
Diesel fuel (kg CO_{2eq} L^{-1})	2.76	[39]
Agricultural machinery (kg CO_{2eq} MJ^{-1})	0.071	[40]
Seeds of maize (kg CO_{2eq} kg^{-1})	15.3	[41]
Seeds of legumes (kg CO_{2eq} kg^{-1})	0.22	[42]
N (kg CO_{2eq} kg^{-1})	1.30	[1]

P_2O_5 (kg CO_{2eq} kg^{-1})	0.20	[1]
K_2O (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 refer to significant differences between treatments at $p \leq 0.05$.

4. Concussions

The highest energy inputs were calculated in technologies with intercropped clovers and alfalfa or about 30% higher than in single maize crop. Maize crops produced higher biomass yields without competing with intercrops regardless of whether it was arid or humid.

Humid vegetative conditions were more favorable for the development of leguminous intercrops than arid conditions. Under wet conditions, the intercrops biomass was about 4 times higher than under dry conditions. Drought caused clover and alfalfa intercrops biomass losses by 23-40% compared with single maize cultivations. Lowe 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%. On the contrary, wet conditions were less suitable for maize and when growing with intercrops they produced about 3-5 t ha^{-1} less dried biomass, and when growing sole - about 6 t ha^{-1} less biomass than in dry conditions. Due to the higher yield of maize biomass in arid season, better energy indicators of the crop were obtained in arid conditions than in humid. The difference between the vegetation conditions was about 122-123 MJ ha^{-1} in all treatments, except for the maize crop with alfalfa, where the difference was 62 MJ ha^{-1}.

According to the CO_2 equivalent, all tested technologies were 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 climate change, the increased number of waterlogging and 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.

Author Contributions: Conceptualization, K.R.; methodology, K.R. and J.B.; software, A.Š., J.B. and K.R.; validation, J.B., K.R.; formal analysis, J.B., A.Š., R.K., A.S. and K.R.; investigation, J.B., A.Š., K.R., A.S., A.J., A.A. and R.K.; resources, J.B., K.R., A.S. and A.Š.; data curation, J.B., K.R. and A.Š.; writing—original draft preparation, K.R., R.K.; A.S. and; writing—review and editing, K.R., R.K., and A.S.; visualization, K.R., A.Š and J.B.; supervision, K.R. All authors have read and agreed to the published version of the manuscript.

Funding: The investigations are partly funded by the Ministry of Agriculture of the Republic of Lithuania, grant "Application of the allelopathic effect in crop agrotechnologies for the implementation of environmental protection and climate change goals", No. MTE-23-3.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Most of the data generated or analyzed during this study are included in the present article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Lal, R. Carbon emission from farm operations. *Environ. Int.* **2004**, *30*(7), 981–990.
2. Failla, S.; Ingrao, 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.; Zabrodskyi, A.; Adamavičienė, A.; Buragienė, S.; Kriaučiūnienė, 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.; Romaneckas, 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.; Plutzar, 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. Romaneckas, K.; Balandaitė, J.; Sinkevičienė, A.; Kimbirauskienė, R.; Jasinskas, A.; Ginelevičius, U.; Romaneckas, 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 Systs.* **2016**, *3*, 29–33.
14. Trimpler, K.; Stockfisch, N.; Märländer, 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. 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.
16. Šarauskis, E.; Romaneckas, K.; Jasinskas, A.; Kimbirauskienė, R.; Naujokienė, V. Improving energy efficiency and environmental mitigation through tillage management in faba bean production. *Energy* **2020**, 209, 118453.
17. 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.
18. Gezer, I.; Acaroglu, M.; Haciseferogullari, H. Use of energy and labour in apricot agriculture in Turkey. *Biomass Bioenergy*. **2003**, 24, 215–219.
19. 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.
20. 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.
21. 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.
22. Agegnehu, G. Yield potential and land-use efficiency of wheat and faba bean mixed intercropping. *Agron. Sustain. Dev.* **2008**, 28, 257–263.
23. Francis C. A.; Porter P. Multicroping. E*ncyclopedia of App. Plant Sci.* (Second Edition). **2017**, 3, 29–33.
24. Hoffman, E.; Cavigelli, M.A.; Camargo, G.; Ryan, M.; Ackroydb, 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.
25. Šarauskis, E.; Masilionytė, L.; Juknevičius, D.; Buragienė, S.; Kriaučiūnienė, Z. Energy use efficiency, GHG emissions, and cost-effectiveness of organic and sustainable fertilisation. *Energy*, **2019,** 172, 1151–1160.
26. 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.

Preprints.org (www.preprints.org) | NOT PEER-REVIEWED | Posted: 21 June 2024 doi:10.20944/preprints202406.1429.v1

27. Whitfield, J. Agriculture and environment: How green was my subsidy? *Nature*, **2006,** *439*(7079), 908–910.
28. 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.
29. 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.
30. 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).
31. 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).
32. 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).
33. 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.
34. 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.
35. 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)
36. Ekologiškos liucernos sėklos / Organic alfalfa seeds. Available online: https://www.vyp.lt/produktas/ekologiskos-liucernos-seklos/ (accessed on 05 02 2024)
37. 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).
38. Brown, H.; Moot, D. 2004. Quality and quantity of chicory, lucerne and red clover production under irrigation. New Zealand Grassland Association.
39. 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.
40. Pishgar-Komleh, S.H.; Ghahderijani, M.; Sefeedpari, P. Energy consumption and CO_2 emissions analysis of potato production based on different farm size levels in Iran. *J. Clean. Prod.* **2012**, 33, 183–191.
41. 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.
42. 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.