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Comparative analysis of energy utilization and environmental consequences throughout the life cycle of alfalfa and silage barley cultivation in different irrigation techniques

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Abstract

The objective of this study was to evaluate the energy efficiency and environmental ramifications of alfalfa and silage barley production in Qazvin province, Iran, under different irrigation systems. The outcomes showed that subsurface irrigation utilized a total input energy of 95667.71 MJ ha-1, whereas surface irrigation had a positive impact on alfalfa production with a total input energy of 902683.07 MJ ha-1. Flood irrigation had the highest input energy of 110973.39 MJ ha-1 and the lowest output energy of 523644.31 MJ ha-1 compared to other irrigation methods for barley. The primary contributors to On-Farm emissions were diesel fuel and chemical fertilizers, but subsurface irrigation systems had lower levels of diesel fuel related pollutants due to reduced usage, while flooding irrigation systems had higher levels of such contaminants. Based on the finding, silage barley cultivation was a better option than alfalfa cultivation in terms of energy consumption and environment.

Keywords: Energy, Environmental impacts, Irrigation, Life cycle assessment

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تجزیه و تحلیل مقایسه‌ای مصرف انرژی و پیامدهای زیست‌محیطی در طول چرخه زندگی کشت یونجه و جو سیلویی در روش های مختلف آبیاری

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چکیده

هدف از این مطالعه بررسی کارایی انرژی و پیامدهای زیست‌محیطی تولید یونجه و جو سیلو در استان قزوین تحت سیستم‌های مختلف آبیاری بود. نتایج نشان داد که آبیاری زیرسطحی از کل انرژی ورودی ۹۵۶۶۷/۷۱ مگاژول در هکتار استفاده کرد، در حالی که آبیاری سطحی با انرژی ورودی ۹۰۲۶۸۳/۰۷ مگاژول در هکتار تأثیر مثبتی بر تولید یونجه داشت. آبیاری غرقابی با ۱۱۰۹۷۳/۳۹ مگاژول در هکتار بیشترین انرژی ورودی و کمترین انرژی خروجی را با ۵۲۳۶۴۴/۳۱ مگاژول در هکتار نسبت به سایر روش‌های آبیاری جو داشت. عوامل اصلی انتشار در مزرعه سوخت دیزل و کودهای شیمیایی بودند، اما سیستم‌های آبیاری زیرسطحی به دلیل کاهش مصرف، سطوح پایین‌تری از آلاینده‌های مربوط به سوخت دیزل داشتند، در حالی که سیستم‌های آبیاری غرقابی دارای سطوح بالاتری از این آلاینده‌ها بودند. بر اساس یافته‌ها، کشت جو سیلویی از نظر مصرف انرژی و محیطی گزینه بهتری نسبت به کشت یونجه بود.

واژه‌های کلیدی: آبیاری، ارزیابی چرخه زندگی، انرژی، تأثیرات زیست‌محیطی

Introduction

The relationship between prosperity and energy is closely intertwined, as increased prosperity typically results in greater demand for energy. This, in turn, often leads to a higher reliance on non-renewable fossil fuels as a primary source of energy. However, it is important to note that fossil fuels are finite resources and currently constitute a significant portion of the world's total energy consumption. Looking ahead, it is clear that the world's energy supply remains heavily reliant on fossil fuels, which has significant implications. Fossil fuels were formed over millions of years through geological processes, and their reserves are finite. However, global consumption of these fuels continues to increase at a rapid pace, which poses various challenges for the future of energy. One of the most pressing concerns is the impact of fossil fuel usage on the environment, as burning these fuels releases greenhouse gases that contribute to climate change and other environmental problems. Moreover, the finite nature of fossil fuel reserves requires us to find alternative energy sources for the long term. To tackle these challenges, researchers and policymakers are exploring various alternative energy sources and technologies such as renewable energy sources like solar, wind, and hydro power, and emerging technologies like nuclear fusion and energy storage. By transitioning to more sustainable and efficient energy systems, we can reduce our dependence on fossil fuels and create a more sustainable energy future (Ali et al., 2017; Saber et al., 2020). Fossil fuel sources play a crucial role in the production of goods and services within the economic system, and they often overshadow other economic activities. As a result, the technology used to produce fuels in varied and useful forms is of great importance to the economy. A significant portion of energy consumption is attributed to agricultural activities. When analyzing farm energy, different types of energy are typically categorized as either direct or indirect, as well as renewable or non-renewable (Lee et al., 2022).

Alfalfa is a vital forage plant globally, providing high-quality fodder that can meet the energy, protein, minerals, and vitamin needs of various livestock. The plant's genetic diversity has contributed to its adaptability to harsh environmental conditions, such as extreme temperatures, dehydration, salinity, and pest resistance (Zhang et al., 2023). The barley field is irrigated multiple times, ranging from 3 to 6 times, depending on the prevailing weather conditions. Autumn barley typically requires irrigation 4 to 5 times, while spring barley needs irrigation 3 times. Insufficient water supply can lead to a reduction in growth rate, premature growth cessation, and premature plant maturation (Qaoud et al., 2022). Iran is known as one of the driest countries globally, experiencing limited rainfall. As a result, the majority of irrigation systems employed in the country rely on surface irrigation. This underscores the critical importance of effective irrigation management. While surface irrigation systems may offer several advantages, such as lower initial investment costs, lower energy supply costs, and ease of maintenance, the development of pressurized irrigation has not led to a widespread shift away from surface irrigation. In fact, surface irrigation is still utilized in more than nine percent of the world's irrigated lands, despite the availability of alternative systems (Pardo et al., 2022). To achieve optimal performance in surface irrigation systems, regular monitoring and evaluation are crucial. Poor irrigation management is the primary cause of the low irrigation efficiency associated with surface irrigation methods. Given the high costs of pressurized irrigation systems, it is significant to improve and modify surface irrigation methods. This includes land leveling, appropriate selection of irrigation methods, proper design, and increasing efficiency (Mawof et al., 2022; Kamran et al., 2022). Furrow irrigation is the prevalent method of irrigating row crops. Unlike other irrigation techniques, water is directed into the channels between two rows of planted crops, rather than flowing over the entire soil surface. Over time, water seeps into the bottom and sides of the furrow, effectively moistening the soil (Rogers et al., 2022).

Efficiency measurement has been the focus of researchers due to its importance in evaluating the performance of a product. In the decision-making problem of simulating the evaluated options and criteria as units and their inputs and outputs, the technique is used in order to rank the options considering the desired criteria (Qi et al., 2015). The linear programming method is a mathematical technique used to optimize a system with linear relationships and constraints. In the context of decision-making units, such as firms or organizations, linear programming can be used to determine the most efficient use of resources to achieve a desired outcome. After a series of optimizations, the linear programming method can determine whether a decision-making unit is located on the efficiency frontier or outside it. The efficiency frontier represents the set of decision-making units that achieve the highest possible level of output from a given set of inputs. Units located on the frontier are considered to be the most efficient, while those located outside the frontier are less efficient. By using linear programming to identify the efficiency frontier, decision-makers can separate effective and ineffective units from each other. This information can be used to make strategic decisions about resource allocation, process improvement, and other factors that affect organizational performance. By focusing resources on the most effective units, organizations can improve their overall efficiency and achieve better outcomes (Azizpanah et al., 2023). The aim of the study is to compare the energy utilization and environmental consequences of alfalfa and silage barley cultivation in different irrigation techniques throughout their respective life cycles. The study intends to analyze and evaluate the energy inputs and outputs, as well as the environmental impacts, associated with the cultivation of these two crops under various irrigation methods.

Materials and methods

The farmers of Qazvin province were selected as the studied community in this research, utilizing a cross-sectional survey method with the coordination and presence of agricultural Jihad experts. To assess farmers' awareness and attitude towards input consumption and crop production, 100 farmers were selected using Equation 1. The required sample size was determined based on similar studies and the sample size calculation formula for cross-sectional studies, with p=0.05 and accuracy d=0.07 (Cochran, 1977). A questionnaire was used to gather information, designed based on previous studies with slight modifications. The questionnaire consisted of three main sections. The first section collected personal information and records such as age, gender, marital status, education level, history of agricultural activity, and type of product. The second section focused on the irrigation method used, while the third section examined farmers' awareness of reducing water consumption. The questionnaire followed a standard structure.

$$n = \frac{\frac{z^2pq}{d^2}}{1 + \frac{1}{N}\left(\frac{z^2pq}{d^2} - 1\right)} \qquad (1)$$

2.1. Sustainability in energy and environmental issues

The energy equation based on sources was used to determine the input energy amount. Agricultural machinery, such as tractors and combines, have a limited economic lifespan, which is gradually consumed as they work in the production process (Talukder et al., 2019). The energy equivalent of machinery is determined by the ratio of energy consumed during the production of raw materials, machinery construction and processing, transportation from the factory to the farm, and energy used for repairs. This value is expressed in MJ per kilogram (Mostashari-Rad et al., 2021). The energy consumption of other inputs was calculated using the equivalent energy values of the consumed and produced inputs (Ali et al., 2017). To estimate fossil fuel consumption, the duration of each operation from start to finish was calculated separately. Based on the tractor and combine drivers' work experience in previous years and working days, the amount of fuel consumed during each operation was calculated using equation 2 (Ghorbani et al., 2011).

$$FT = t \times FG \qquad (2)$$

where FT is the fuel needed to carry out agricultural operations at the level of one hectare (liters per ha), t is the duration of the machinery operation (hours per ha) and FG is the fuel required by the tractor in one hour of operations (liters per hour). Table 1 showed energy coefficients in alfalfa and silage barley production.

Table 1. Energy inputs-outputs and energy coefficients in alfalfa and silage barley production.

Items	Unit	Energy equivalent (MJ unit^{-1})	References
A. Inputs			
1. Human labor	h	1.96	(Kaab et al., 2019)
2. Machinery	kg yr	62.7	(Hosseinzadeh-Bandbafha et al., 2018)
3. Diesel fuel	L	56.31	(Abdi et al., 2012)
4. Chemical fertilizers	kg		
(a) Nitrogen		66.14	(Kaab et al., 2021)
(b) Phosphate (P_2O_5)		12.44	(Kitani, 1999)
(b) Potassium (K)		11.15	(Kitani, 1999)
5. Farmyard manure	kg	0.3	(Kitani, 1999)
6. Biocides	kg	120	(Omid et al., 2018)
7. Electricity	kWh	12	(Sefeedpari et al., 2014)
8. Alfalfa seed	kg	28.1	(Kitani, 1999)
9. Silage barley seed	kg	14.70	(Kitani, 1999)
B. Outputs	kg		
1. Alfalfa		15.8	(Kitani, 1999)
2. Silage barley		14.7	(Kitani, 1999)

The four primary energy indicators are energy consumption efficiency, energy productivity, specific energy, and net energy (Equations 3 to 6). The energy consumption efficiency index measures the amount of energy produced per MJ ha^{-1} of energy consumed during production (Azizpanah et al., 2023). A higher ratio indicates greater energy efficiency. The energy productivity index determines the amount of output obtained per MJ ha^{-1} of input energy. The specific energy index is calculated by dividing the total energy input by the product's performance, and a higher value indicates greater energy waste. Finally, the net energy index represents the net energy output (Soltani et al., 2023).

$$\text{Energy use efficiency } = \frac{\text{Output energy (MJ)}}{\text{Input energy (MJ)}} \qquad (3)$$

$$\text{Energy productivity } = \frac{\text{Production (kg)}}{\text{Input energy (MJ)}} \qquad (4)$$

$$\text{Specific energy } = \frac{\text{Input energy (MJ)}}{\text{Production (kg)}} \qquad (5)$$

$$\text{Net energy } = \text{ Output energy (MJ) - Input energy (MJ)} \qquad (6)$$

Numerous studies have underscored the importance of assessing greenhouse gas emissions in energy systems due to their potential impact. These studies typically report data on CO_2 equivalent emissions, considering both CO2 and other greenhouse gases in the evaluation (Roy et al., 2009). Life cycle assessment (LCA) involves collecting and analyzing inputs, outputs, and potential environmental impacts of a product system throughout its life cycle (Rebitzer et al., 2004). The term "product" in LCA is broadly defined to include physical goods and services, encompassing all goods and services at both the strategic and operational levels. LCA strives to provide a quantitative assessment wherever possible, but in cases where quantitative data is unavailable, it considers qualitative aspects to provide a comprehensive view of the environmental impacts (Elyasi et al., 2022).

At the strategic level, similar applications can be identified with respect to the commercial and political strategies of governments. The approach for implementing an LCA project depends on the intended use of its results (Taherzadeh-Shalmaei et al., 2023). LCA reviews typically include four stages: goal and scope definition, inventory analysis, impact assessment, and interpretation of results. The objective is to reduce environmental emissions associated with livestock feed production. To achieve stability and optimization in these systems, it is essential to determine the emissions of each system first (Saber et al., 2020). The scope of an LCA should clearly define the functionality or performance characteristics of the system under study. The functional unit (FU) should be aligned with the study's purpose and scope. One of the primary objectives of the FU is to establish a reference point to normalize input and output data (Nunes et al., 2017). Quantitative and qualitative data entered in the inventory step should be collected for each unit within the system boundary. One ton of product is defined as the FU, as depicted in Figure 1, which illustrates the study system's boundary. If data is sourced publicly, the reference should be specified, and equivalent was utilized to calculate the data (IPCC, 2006; ISO, 2006). Data that may be relevant to the study's conclusion should include details of the data collection process, the time period for which the data was collected, and information about data quality indicators (Rajendran and Han, 2023). The impact categories selected should represent the set of input and output impacts of the product system based on each category's endpoint indicators. The life cycle impact assessment phase should be carefully planned to achieve the LCA study's purpose and scope (Henderson et al., 2023).

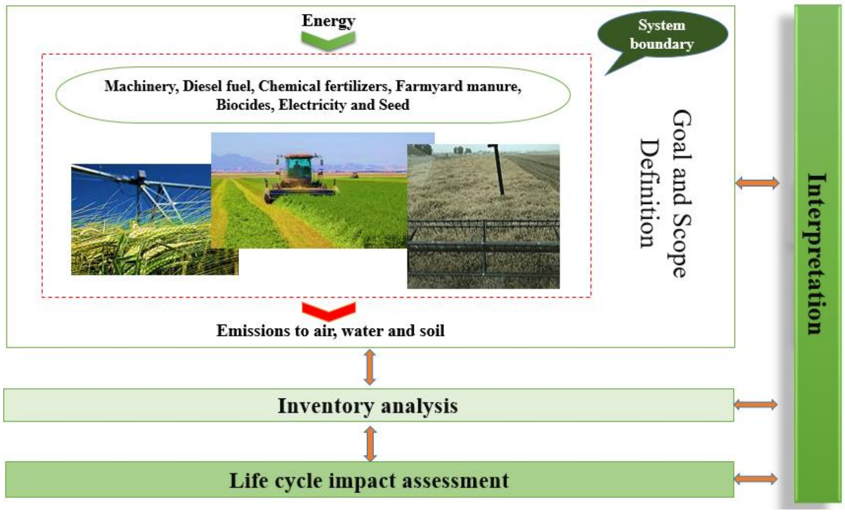


Fig. 1. The boundary of alfalfa and silage barley production system with stages of LCA.

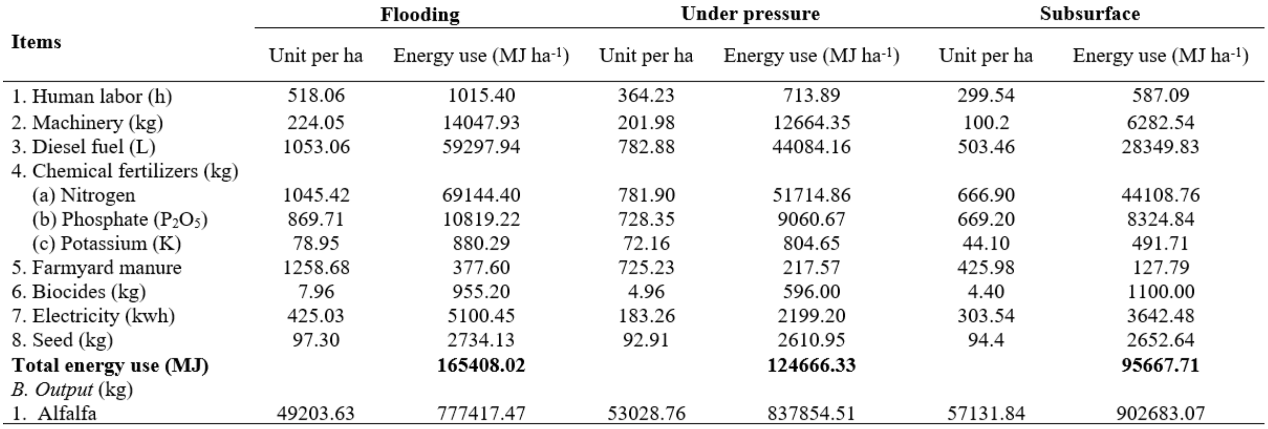
Results and discussion

3.1. Input-output energy analysis

The energy consumption of inputs under different irrigation conditions was determined by averaging the collected samples. Table 2 displays the energy input and output of alfalfa production, with the consumption of each input differing under different irrigation methods. Each input was evaluated according to its FU, with the energy equivalent obtained from various sources facilitating the comparison of energy consumption across irrigation methods. The total energy consumption of inputs with subsurface irrigation was 95667.71 MJ ha^{-1}. This figure represents a lower energy consumption than irrigation under pressure (124666.33 MJ ha^{-1}) and flood irrigation (165408.02 MJ ha^{-1}). Alfalfa production energy under surface irrigation conditions was reported at a positive point with 902683.07 MJ ha^{-1}. The output energy under flood irrigation, however, was more negative than the other two methods at 777414.47 MJ ha^{-1}.

Figure 2 illustrates a comparison of the consumption percentage of each input in relation to one another and to each irrigation method for the alfalfa crop. Nitrogen fertilizers are of particular interest to farmers as they can increase crop yield, but require more energy for production. Nitrogen fertilizer has an energy share of over 40%. The timing of nitrogen fertilizer application is a critical management method to increase nitrogen use efficiency. In order to use nitrogen fertilizer accurately and efficiently, it is essential to have a correct understanding of the plants' needs during the growing season. The next highest input is diesel fuel, accounting for 35.85% of energy consumption in flood irrigation. The use of irrigation equipment in subsurface irrigation consumes more electricity (3.81%) than other methods. Training farmers to use pumping systems during non-peak hours of electricity consumption, maintaining and optimizing pumping systems, and using high-efficiency electric pumps can help reduce energy consumption.

Table 2. Amounts of inputs-outputs energy in alfalfa production under different irrigation.



Items	**Flooding**		**Under pressure**		**Subsurface**	
	Unit per ha	Energy use (MJ ha^{-1})	Unit per ha	Energy use (MJ ha^{-1})	Unit per ha	Energy use (MJ ha^{-1})
1. Human labor (h)	518.06	1015.40	364.23	713.89	299.54	587.09
2. Machinery (kg)	224.05	14047.93	201.98	12664.35	100.2	6282.54
3. Diesel fuel (L)	1053.06	59297.94	782.88	44084.16	503.46	28349.83
4. Chemical fertilizers (kg)						
(a) Nitrogen	1045.42	69144.40	781.90	51714.86	666.90	44108.76
(b) Phosphate (P_2O_5)	869.71	10819.22	728.35	9060.67	669.20	8324.84
(c) Potassium (K)	78.95	880.29	72.16	804.65	44.10	491.71
5. Farmyard manure	1258.68	377.60	725.23	217.57	425.98	127.79
6. Biocides (kg)	7.96	955.20	4.96	596.00	4.40	1100.00
7. Electricity (kwh)	425.03	5100.45	183.26	2199.20	303.54	3642.48
8. Seed (kg)	97.30	2734.13	92.91	2610.95	94.4	2652.64
Total energy use (MJ)		**165408.02**		**124666.33**		**95667.71**
B. Output (kg)						
1. Alfalfa	49203.63	777417.47	53028.76	837854.51	57131.84	902683.07

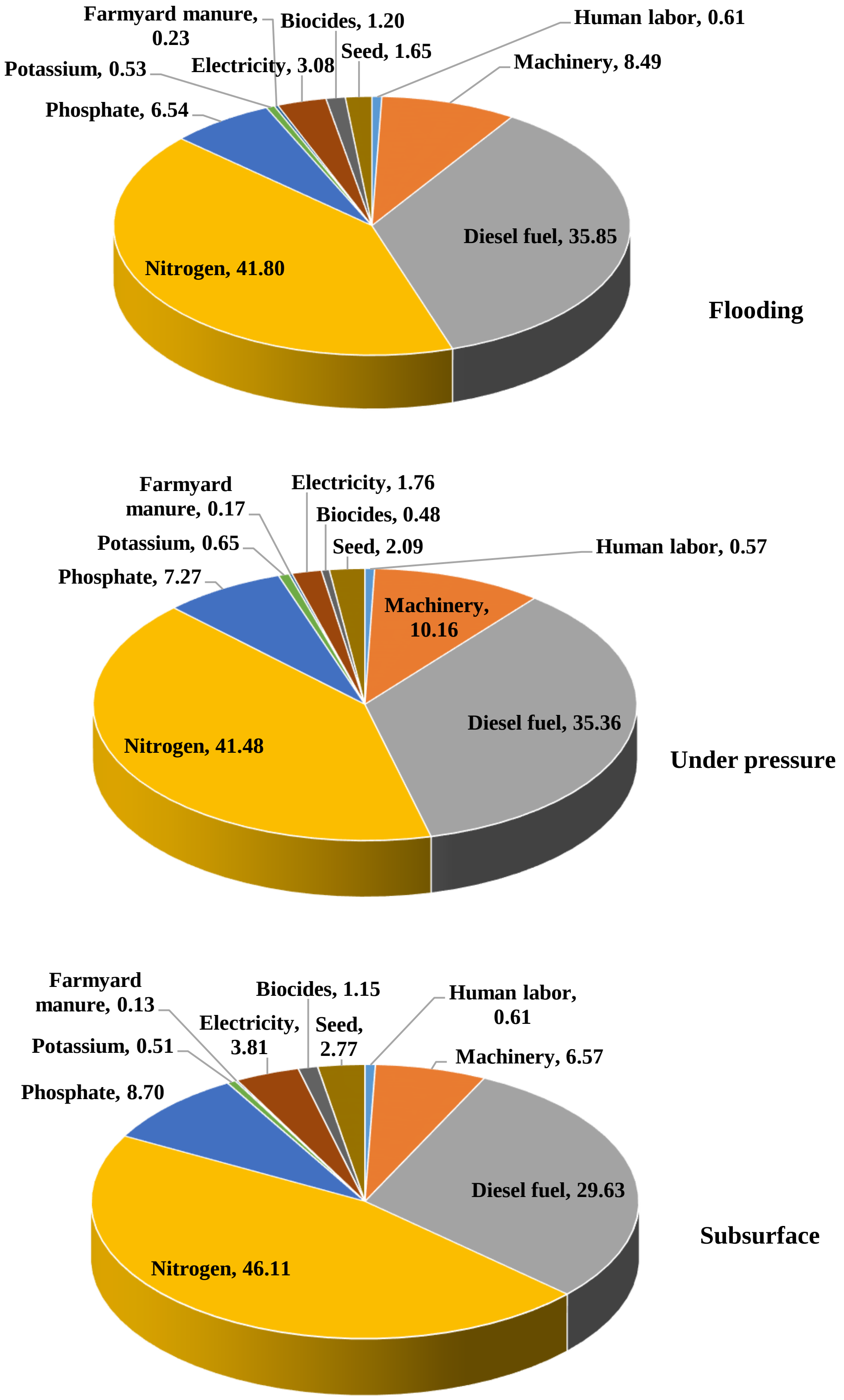


Fig. 2. Contributions of energy sources in alfalfa production under different irrigation.

Given the limited water resources in Iran, it is crucial to carefully plan for the optimal use of available water resources for agriculture, which is the largest water consumer. Table 3 presents the energy characteristics for barley production. Similar to alfalfa, the flood irrigation method results in the highest input energy (110973.39 MJ ha^{-1}) and the lowest output energy (523644.31 MJ ha^{-1}) for barley compared to the other two irrigation methods. As a result, comparing these two crops, barley production is more energy-efficient. It is possible that its production energy is lower than that of alfalfa. Therefore, selecting each feature according to farmers' goals can be effective in farm management. Figure 2b explores the percentage contribution of inputs to energy consumption in barley production. The results in this figure are markedly different from those in Figure 3. Diesel fuel is the primary energy consumer in barley production, accounting for the highest percentage. Many machines are used at different stages of production, with machine use accounting for approximately 20% of energy consumption. Improving the structure and performance of mechanization can help optimize energy consumption from a management perspective. It is crucial to promote the use of machinery and equipment suitable for agricultural operations and cultivated areas to increase efficiency, reduce operation time, and fuel consumption depending on the product variety. The use of nitrogen fertilizers during barley cultivation is lower, allowing for safer use for better product performance. The use of irrigation equipment has increased electricity consumption in the surface irrigation method to 10.84%.

Table 3. Amount of inputs-outputs energy in silage barley production under different irrigation.

Items	**Flooding**		**Under pressure**		**Subsurface**	
	Unit per ha	Energy use (MJ ha^{-1})	Unit per ha	Energy use (MJ ha^{-1})	Unit per ha	Energy use (MJ ha^{-1})
1. Human labor (h)	326.62	640.18	300.93	589.83	225.32	441.63
2. Machinery (kg)	375.33	23533.66	283.18	17755.60	221.74	13903.10
3. Diesel fuel (L)	885.50	49862.50	721.08	40604.20	544.82	30678.81
4. Chemical fertilizers (kg)						
(a) Nitrogen	251.47	16632.55	215.75	14269.71	194.08	12836.45
(b) Phosphate (P_2O_5)	126.11	1568.83	125.47	1560.81	82.94	1031.77
(c) Potassium (K)	78.95	880.29	72.17	804.66	44.10	491.72
5. Farmyard manure	1803.21	540.96	990.22	297.07	733.30	219.99
6. Biocides (kg)	7.96	955.20	4.97	1241.67	4.40	541.00
7. Electricity (kwh)	1002.07	12024.90	758.53	9102.40	565.22	6782.64
8. Seed (kg)	224.41	3298.86	215.78	3172.02	204.36	3004.09
Total energy use (MJ)		**110973.39**		**89397.94**		**66927.11**
B. Output (kg)						
1. barley silage	35622.10	523644.31	37272.73	547909.18	42749.54	628418.24

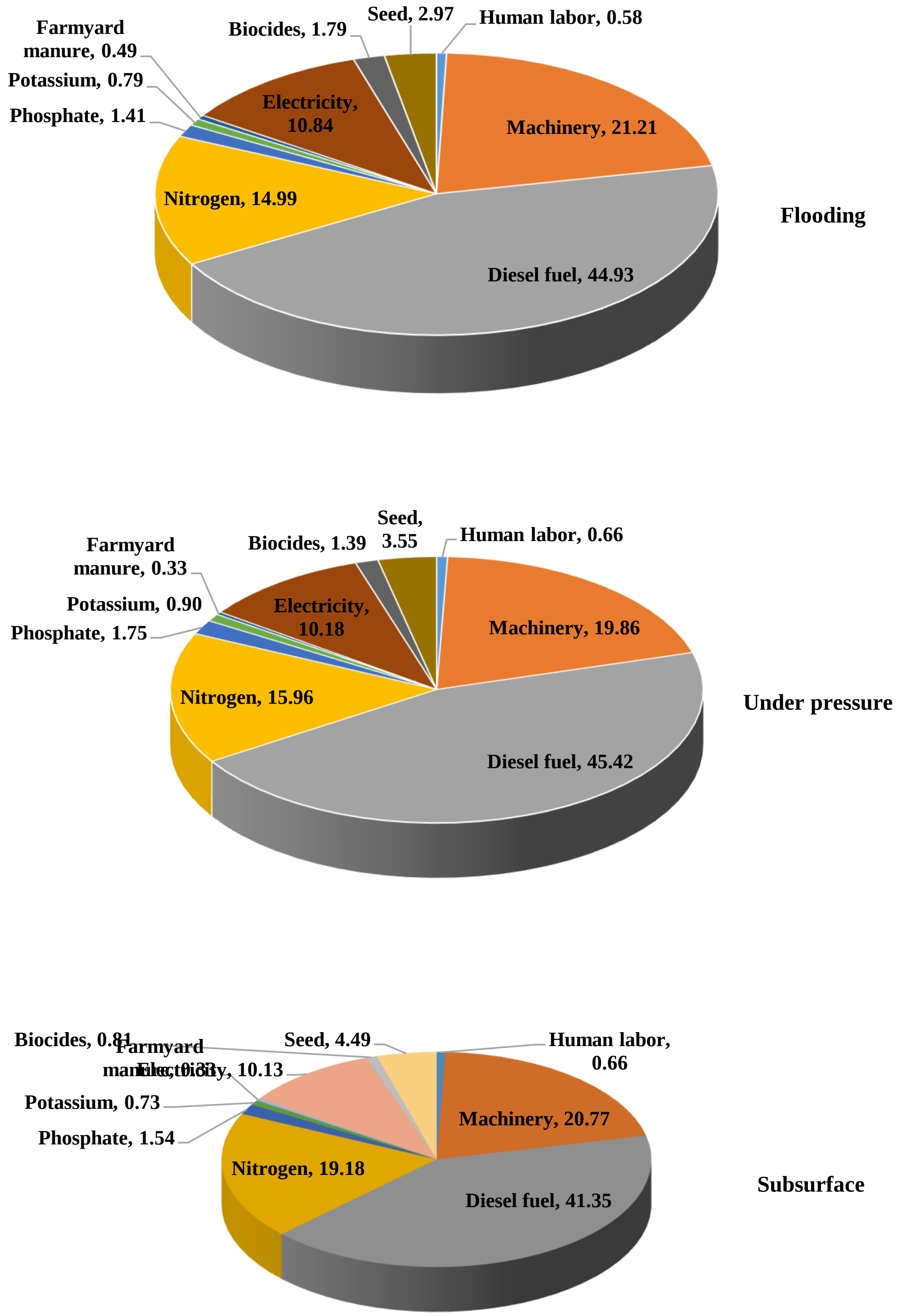


Fig. 3. Contributions of energy sources in silage barley production under different irrigation.

Table 4 and 5 provide a comparison of the energy indices for alfalfa and barley. The energy ratio in the surface irrigation method is highly satisfactory for both crops. The higher energy ratio for alfalfa compared to barley suggests that alfalfa cultivation provides more energy to consumers. The high energy productivity in barley production indicates that less energy is required per kilogram of crop compared to alfalfa cultivation. Energy intensity results are also contrary to energy productivity. Net energy, which yields a positive outcome, has reached its highest level (807015.35 MJ ha-1) in alfalfa cultivation under surface irrigation conditions.

Table 4. Energy indices in alfalfa production under different irrigation.

Items	Flooding	Under pressure	Subsurface
Energy use efficiency (ratio)	4.71	6.27	9.43
Energy productivity (kg MJ^{-1})	0.29	0.42	0.59
Specific energy (MJ kg^{-1})	3.40	2.37	1.69
Net energy gain (MJ ha^{-1})	612009.44	713188.17	807015.358

Table 5. Energy indices in silage barley production under different irrigation.

Items	Flooding	Under pressure	Subsurface
Energy use efficiency (ratio)	4.27	6.14	9.41
Energy productivity (kg MJ^{-1})	0.32	0.42	0.64
Specific energy (MJ kg^{-1})	3.13	2.42	1.58
Net energy gain (MJ ha^{-1})	412670.92	458511.24	561491.13

3.2. LCA analysis

The initial stage of the LCA process involves data collection and analysis to identify the inputs and outputs of the product life cycle. Accurate data collection is crucial, as data shortages can be a significant challenge. To ensure transparency and accuracy, reference sources must be specified if data is collected from public sources. The Eco-Invent database is a commonly used resource in LCA. The data collected should be relevant to the FU defined in the LCA objectives. The inventory flow should be categorized depending on the scope of the system being analyzed. Off-Farm emissions can be used to calculate environmental emissions related to input production processes. It is essential to note that all activities within the system boundary, including upstream and downstream processes, should be accounted for in the collected data. Furthermore, data quality should be assessed, and uncertainties should be identified and addressed in the analysis. This step is critical in ensuring the accuracy and reliability of the LCA results. The production inputs for alfalfa and silage barley are used in various irrigation systems, resulting in On-Farm emissions. Table 6 and 7 present the outcomes of this analysis. Diesel fuel and chemical fertilizers contribute the most to On-Farm emissions. However, in subsurface irrigation systems, the level of diesel fuel pollutants is lower due to the reduced use of diesel fuel. Conversely, flood irrigation systems tend to have a higher prevalence of contaminants associated with diesel fuel.

Table 6. On-Farm emissions in alfalfa production under different irrigation based on 1 hectare.

	Flooding	**Under pressure**	**Subsurface**
1. Emissions by diesel fuel to air (kg)			
(a). Carbon dioxide (CO_2)	4417.69	3284.26	2112.06
(b). Sulfur dioxide (SO_2)	1.42	1.06	0.68
(c). Methane (CH_4)	0.18	0.13	0.08
(d). Benzene	0.01	0.007	0.004
(e). Cadmium (Cd)	0.00001	0.00001	0.000007
(f). Chromium (Cr)	0.00007	0.00005	0.00003
(g). Copper (Cu)	0.002	0.001	0.001
(h). Dinitrogen monoxide (N_2O)	0.16	0.12	0.08
(i). Nickel (Ni)	0.00009	0.00007	0.00004
(j). Zink (Zn)	0.001	0.001	0.0006
(k). Benzo (a) pyrene	0.00004	0.00003	0.00002
(l). Ammonia (NH_3)	0.02	0.02	0.01
(m). Selenium (Se)	0.00001	0.00001	0.000007
(n). PAH (polycyclic hydrocarbons)	0.004	0.003	0.002
(o). Hydro carbons (HC, as NMVOC)	4.03	2.99	1.92
(p). Nitrogen oxides (NOx)	62.85	46.72	30.05
(q). Carbon monoxide (CO)	8.89	6.61	4.25
(r). Particulates (b2.5 µm)	6.34	4.71	3.03
2. Emissions by fertilizers to air (kg)			
(a). Ammonia (NH3) by chemical fertilizers	126.94	94.94	80.98
3. Emissions by fertilizers to water (kg)			
(a). Nitrate	138.89	103.88	88.60
(b). Phosphate	18.98	15.90	14.60
4. Emission by N_2O of fertilizers and soil to air (kg)			
(a). Nitrogen oxides (NOx)	219.53	164.19	140.04
5. Emission by human labor to air (kg)			
(a). Carbon dioxide (CO_2)	362.64	254.96	209.67
6. Emission by heavy metals of fertilizers to soil (mg)			
(a). Cadmium (Cd)	84997.32	70621.51	64572.82
(b). Copper (Cu)	207898.40	171725.70	156247.47
(c). Zink (Zn)	1885570.55	1560158.23	1422750.63
(d). Lead (Pb)	5788757.98	4341571.25	3710385.05
(e). Nickel (Ni)	197886.58	163793.16	149315.06
(f). Chromium (Cr)	1165059.65	968463.51	885568.56
(g). Mercury (Hg)	721.24	595.25	539.54

Table 7. On-Farm emissions in silage barley production under different irrigation based on 1 hectare.

	Flooding	**Under pressure**	**Subsurface**
1. Emissions by diesel fuel to air (kg)			
(a). Carbon dioxide (CO_2)	3714.75	3025.01	2285.57
(b). Sulfur dioxide (SO_2)	1.20	0.97	0.73
(c). Methane (CH_4)	0.15	0.12	0.09
(d). Benzene	0.008	0.007	0.005
(e). Cadmium (Cd)	0.00001	0.00001	0.000007
(f). Chromium (Cr)	0.00005	0.00004	0.00003
(g). Copper (Cu)	0.002	0.001	0.001
(h). Dinitrogen monoxide (N_2O)	0.14	0.11	0.08
(i). Nickel (Ni)	0.00008	0.00006	0.00005
(j). Zink (Zn)	0.001	0.0009	0.0007
(k). Benzo (a) pyrene	0.00003	0.00002	0.00002
(l). Ammonia (NH_3)	0.02	0.01	0.01
(m). Selenium (Se)	0.00001	0.00001	0.000007
(n). PAH (polycyclic hydrocarbons)	0.003	0.003	0.002
(o). Hydro carbons (HC, as NMVOC)	3.39	2.76	2.08
(p). Nitrogen oxides (NOx)	52.85	43.04	32.51
(q). Carbon monoxide (CO)	7.47	6.09	4.60
(r). Particulates (b2.5 µm)	5.33	4.34	3.28
2. Emissions by fertilizers to air (kg)			
(a). Ammonia (NH3) by chemical fertilizers	30.53	26.19	23.56
3. Emissions by fertilizers to water (kg)			
(a). Nitrate	33.41	28.66	25.78
(b). Phosphate	2.75	2.73	1.81
4. Emission by N_2O of fertilizers and soil to air (kg)			
(a). Nitrogen oxides (NOx)	52.80	45.30	40.75
5. Emission by human labor to air (kg)			
(a). Carbon dioxide (CO_2)	228.63	210.65	157.72
6. Emission by heavy metals of fertilizers to soil (mg)			
(a). Cadmium (Cd)	12937.82	12663.67	8679.37
(b). Copper (Cu)	33330.50	32208.95	22598.33
(c). Zink (Zn)	294455.90	285885.13	199390.19
(d). Lead (Pb)	1379768.03	1186421.87	1062617.63
(e). Nickel (Ni)	31085.83	30178.19	21008.60
(f). Chromium (Cr)	177428.94	173770.68	118842.18
(g). Mercury (Hg)	121.32	116.62	81.88

Table 8 displays the damage assessment results for different production scenarios of alfalfa and silage barley under various irrigation methods, using the ReCiPe 2016 method. Resources were found to have the highest environmental impact, while human health had the least impact. There are more studies available on flood irrigation systems than subsurface irrigation systems for both crops. Additionally, greenhouse gas emissions associated with flood irrigation systems were higher than those of under pressure and subsurface irrigation systems for both crops. Regarding pollutants, the resources category had a more significant impact on alfalfa production than silage barley production in flood irrigation systems for both crops. Mostashari-Rad et al. (2021) evaluated the life cycle of horticultural products using the ReCiPe 2016 method and found that the resources category had a higher impact than the ecosystem and human health categories for citrus, hazelnut, kiwifruit, tea, and watermelon. Litskas et al. (2017), Bosco et al. (2011), and Point et al. (2012) reported greenhouse gas emissions of 0.155 kg CO2eq, 0.15 to 0.3 kg CO2eq, and 0.8 kg CO2eq, respectively. Nutrient management was found to contribute 49% to ozone layer depletion, 65% to global warming, 79% to freshwater aquatic ecotoxicity, and 92% to acidification (Point et al., 2012).

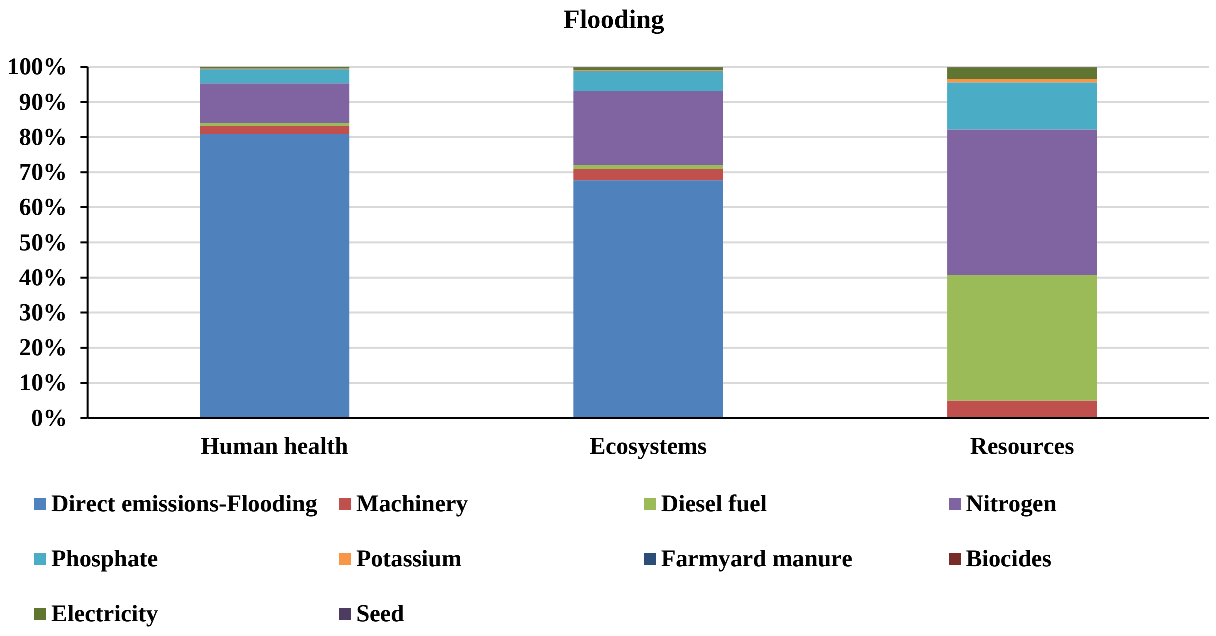
Table 8. Values of the damage assessment per one ton in different production of alfalfa and silage barley under different irrigation.

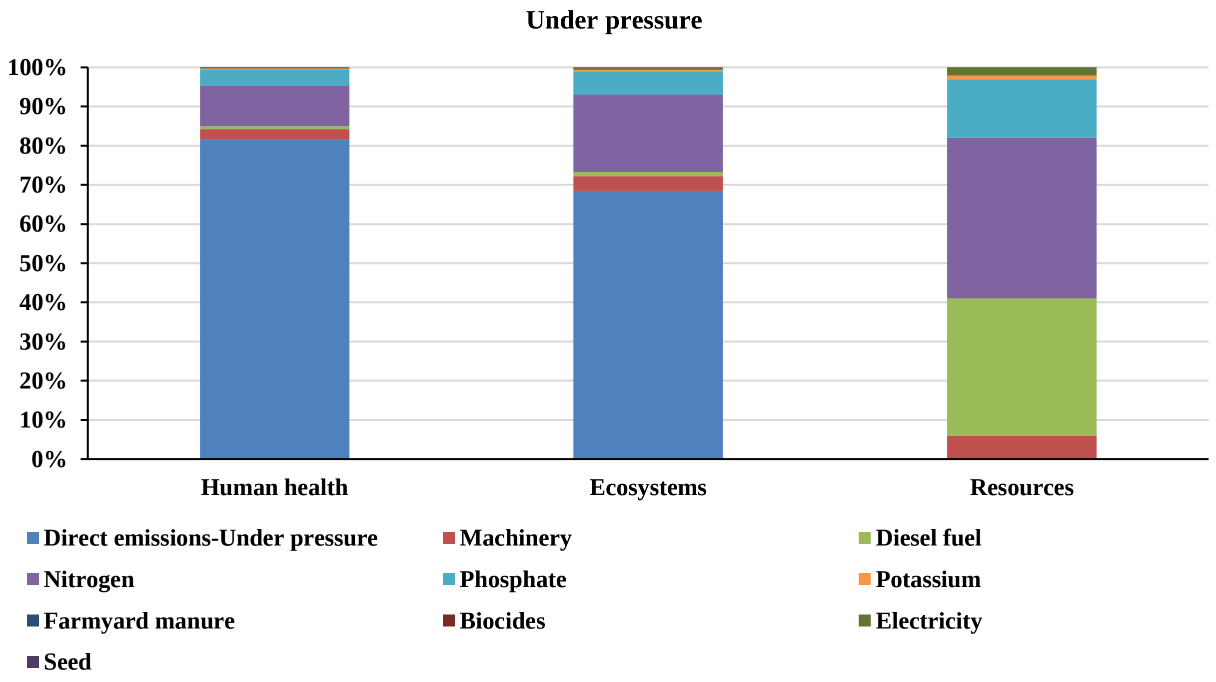
Items	**Unit**	**Alfalfa**			**Silage barley**		
		Flooding	**Under pressure**	**Subsurface**	**Flooding**	**Under pressure**	**Subsurface**
Human health	DALY [a]	0.02	0.02	0.01	0.01	0.008	0.005
Ecosystems	species.yr [b]	2.39E-05	1.76E-05	1.39E-05	1.11E-05	9.10E-06	6.12E-06
Resources	USD2013	29.38	20.63	14.96	24.13	18.76	12.73

[a] DALY: disability adjusted life years. A damage of 1 is equal to: loss of 1 life year of 1 individual, or 1 person suffers 4 years from a disability with a weight of 0.25.

[b] species.yr: the unit for ecosystems is the local species loss integrated over time.

Figures 4 and 5 depict the proportion of emissions from each input in alfalfa and silage barley production under different irrigation methods. Direct emissions from both production methods have a considerable impact on human health, with alfalfa and silage barley accounting for 80% and 65% of emissions, respectively. Diesel fuel and nitrogen fertilizer contribute the most to the environmental impact on resources, accounting for over 50% of the total impact. Proper nitrogen fertilizer management is crucial for crop growth and yield, and researchers and farmers should prioritize its appropriate use. In many regions, there are strict regulations on the use of chemical fertilizers in agriculture to prevent excessive amounts of elements from entering the environment. This not only protects the environment and human health but also has economic benefits such as reducing costs, improving efficiency, and conserving resources. Electricity and diesel fuel have a more significant impact on silage barley production than in alfalfa production. Steenwerth et al. (2015) proposed two fertilizer management methods: mineral fertilizer and compost fertilizer. Considering the appropriate use of fertilizers and efficient farming practices is essential to minimize environmental impacts and ensure sustainable agricultural production.


Flooding
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Human health
Ecosystems
Resources
Direct emissions-Flooding
Machinery
Diesel fuel
Nitrogen
Phosphate
Potassium
Farmyard manure
Biocides
Electricity
Seed


Under pressure
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Human health
Ecosystems
Resources
Direct emissions-Under pressure
Machinery
Diesel fuel
Nitrogen
Phosphate
Potassium
Farmyard manure
Biocides
Electricity
Seed

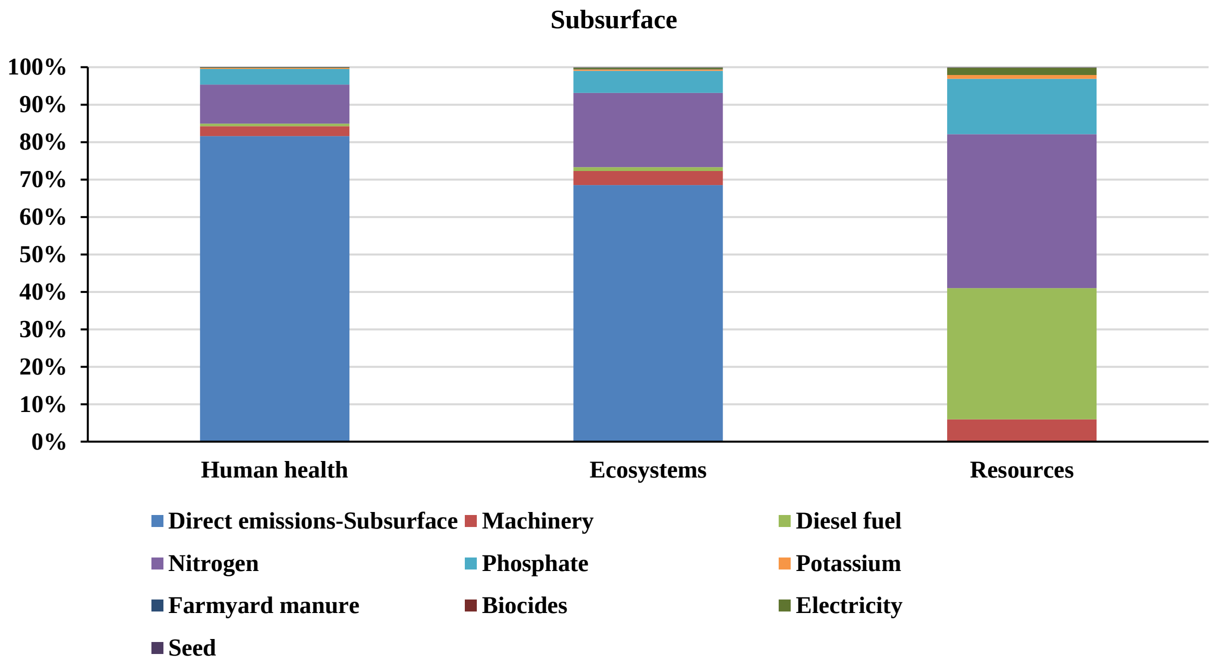
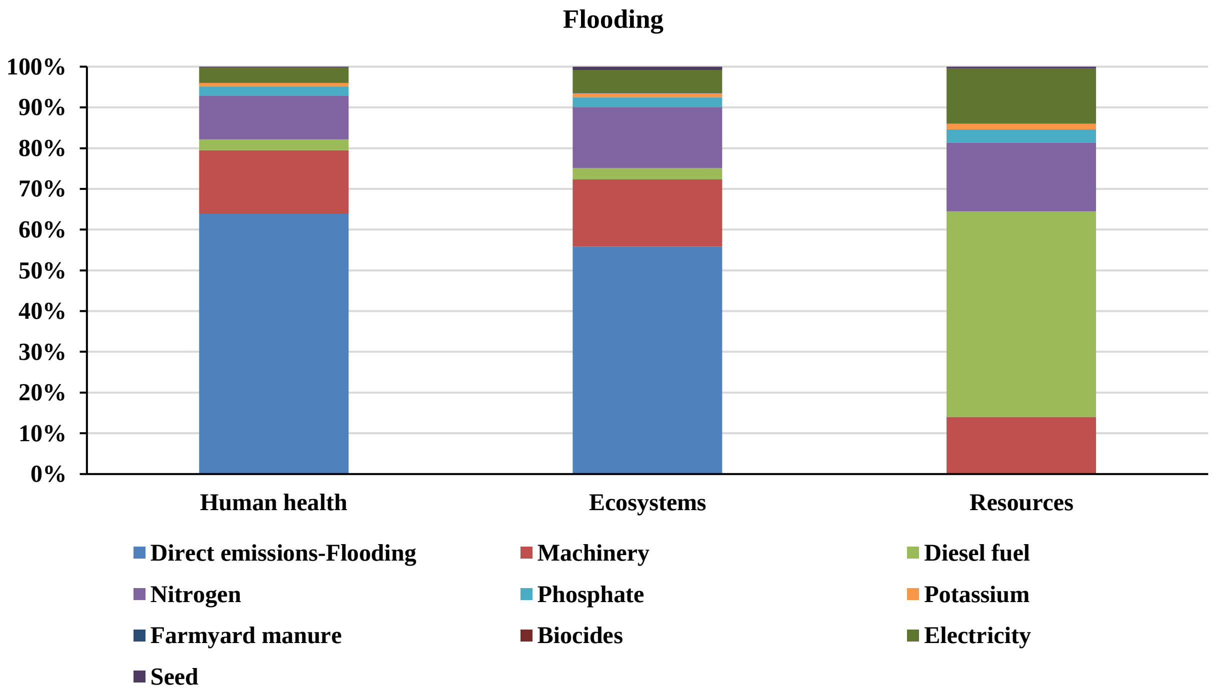


Fig. 4. Contribution of different inputs in the damages categories for alfalfa production under different irrigation.



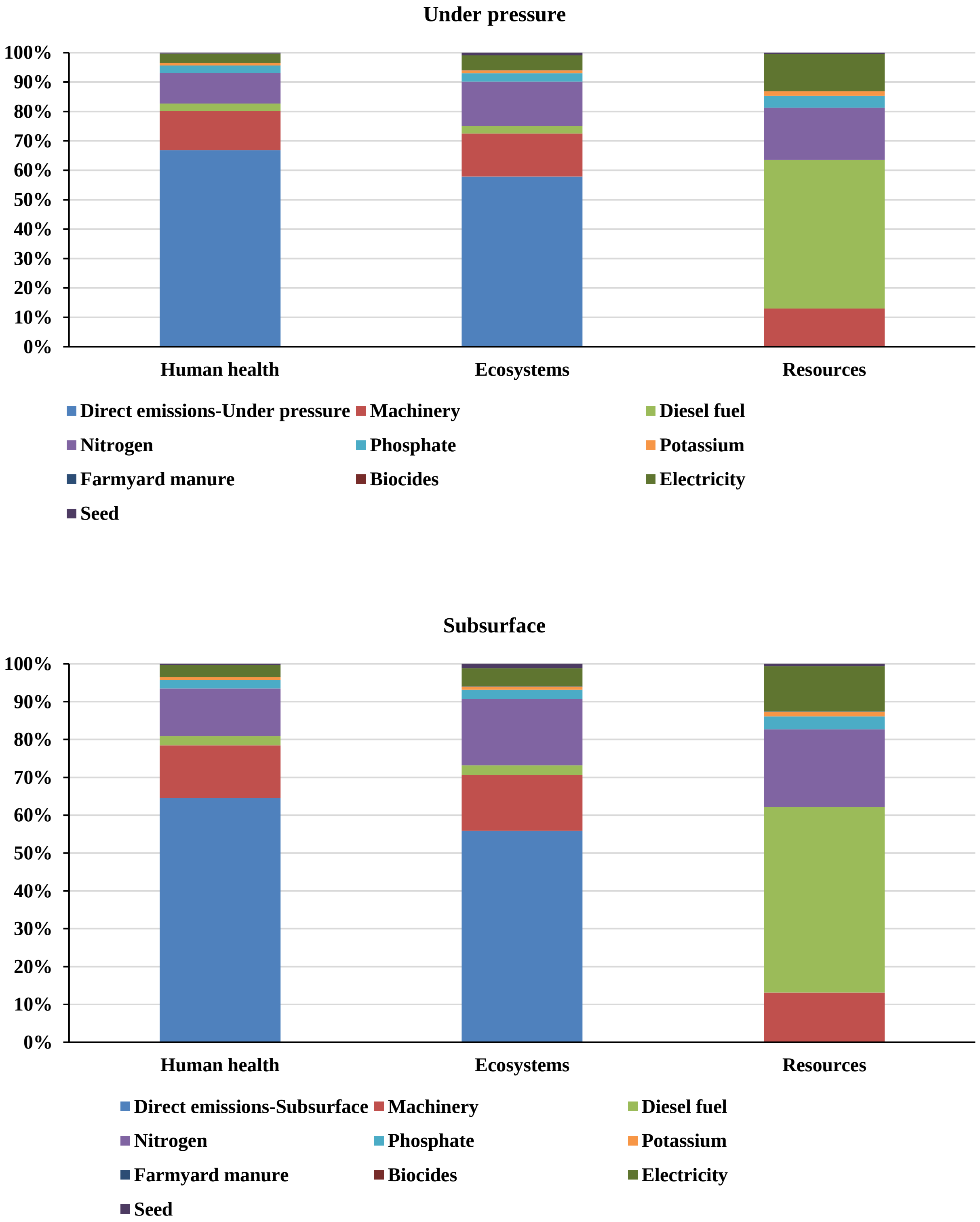


Fig. 5. Contribution of different inputs in the damages categories for silage barley production under different irrigation.

4. Conclusions

In conclusion, the comparative analysis of energy utilization and environmental consequences throughout the life cycle of alfalfa and silage barley cultivation in different irrigation techniques reveals that both crops have their advantages and disadvantages. Alfalfa cultivation requires less water and energy compared to silage barley, but it has a higher environmental impact due to its higher nitrogen fertilization requirements. On the other hand, silage barley has a higher water and energy requirement, but it has a lower environmental impact due to its lower nitrogen fertilization requirements. The choice of irrigation technique also plays a significant role in determining the energy utilization and environmental consequences of crop cultivation. Drip irrigation is the most efficient irrigation technique, requiring less water and energy compared to flood and sprinkler irrigation. However, its high initial cost may deter farmers from adopting it. Overall, the comparative analysis highlights the need for farmers to consider the trade-offs between energy utilization and environmental consequences when choosing between alfalfa and silage barley cultivation and selecting an irrigation technique. It also emphasizes the importance of adopting sustainable agricultural practices to minimize the environmental impact of crop cultivation.

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