Journal of Agricultural Engineering 2025; volume LVI:1723

Evaluating the efficiency of energy use in cultivation of medicinal plants: a case study on garden thyme and peppermint employing life cycle assessment and support vector machine modeling

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Abstract

This study utilized two questionnaires to assess energy consumption in farms and the energy yield from garden thyme and peppermint over multiple years. During face-to-face meetings with farmers, 55 questionnaires were completed. The Ecoinvent database was utilized to gather necessary information, and Simapro software was employed for LCA calculations. Additionally, the study utilized the SVM model to predict the energy output of garden thyme and peppermint. The findings revealed that electricity accounted for the highest energy consumption in thyme cultivation, representing 41% for garden thyme and 36% for peppermint of the total energy usage. Urea fertilizer played a significant role in energy consumption for both peppermint and garden thyme agriculture, comprising 34% of the total energy usage after electricity. Furthermore, the energy production to consumption ratio for five years of garden thyme and peppermint cultivation stood at approximately 2.2 and 2.17, respectively. The results demonstrated that the SVM model exhibited high accuracy and low error rates in estimating energy output for garden thyme and peppermint. The evaluation criteria for actual versus predicted data yielded an R2 value of 0.9796 and RMSE of 0.0367 for garden thyme, and an R2 value of 0.9765 and RMSE of 0.0081 for peppermint. These metrics indicate a strong performance in estimating output energy for both plants.

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Key words: medicinal plants; life cycle assessment; support vector machine; sustainability.

Contributions: all the authors made a substantive intellectual contribution, read and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

Conflict of interest: the authors declare that they have no competing interests, and all authors confirm accuracy.

Received: 30 May 2024.
Accepted: 5 August 2024.

Journal of Agricultural Engineering 2025; LVI:1723
doi:10.4081/jae.2025.1723

Introduction

Garden thyme is a woody plant, and it has a hard stem. It originates in the Mediterranean region and grows in southern Europe densely. This plant grows in semi-arid areas of New Zealand in large areas. To clarify, garden thyme and peppermint cultivation can be energy-intensive due to several factors. These may include the need for proper soil preparation, irrigation, pest control measures, harvesting techniques, and post-harvest processing. Both crops often require specific growing conditions and care to thrive, which can contribute to increased energy consumption compared to other crops. Additionally, the extraction of essential oils from these herbs can be a laborious and energy-intensive process. These factors make understanding the energy requirements of garden thyme and peppermint cultivation important for optimizing production efficiency and sustainability (Kulpa *et al.*, 2018). It has straight, more or less woody roots and many branches. The stem is straight and quadrangular, and its height is different, but it depends on the climatic conditions of the place where it grows, and its stem is between 20 to 50 cm. The basal stem is wooden, while the upper part is darker green and has many branches (Shokoohi *et al.*, 2022). As garden thyme flourishes, its branching stem becomes increasingly dense with growth. A Mediterranean plant, garden thyme thrives in hot, sunny conditions and is well-suited to dry climates and drought. Preferring high altitudes and not tolerant of flood irrigation, it does not require excessive watering. In colder seasons, without snow cover, garden thyme may be susceptible to cold temperatures, as it thrives in full sun and warmth, enhancing the production of its essential oil (Noroozisharaf and Kaviani, 2018). It is recommended to cultivate garden thyme in sunny areas and the southern slope of the hill. Peppermint is a perennial and fragrant herb (Noroozisharaf and Kaviani, 2018). Peppermint is a perennial herb with creeping stems (stalk), underground stems (creeping underground stems), and square stems that are purple-red color, on which the oval leaves are placed opposite each other. Peppermint flowers are purple, and their fruit looks like a red capsule with seeds without germination. It is possible to produce peppermint seeds by reproducing the parent plant, which generates a new plant, and plants can propagate using budding or cutting (vegetative reproduction) (Mahendran and Rahman, 2020). This plant grows to a height of 30-90 cm, and it has a smooth stem that peppermint stem has a quadrangular surface in cross-section and its roots are sprayed and fleshy, and the leaves are dark green with red veins, 4-9 cm long and width of 1/5-4 cm. The stems and leaves are usually fluffy. The peppermint flowers are purple, 6-8 mm long, with the cup-shaped flower of 4 petals to 5 mm in diameter, which flowers form a tight spiral and whorl around the stem. These long-blooming flowers from mid-summer well into the fall (late summer), but blooms are barren flowers. Therefore, peppermint propagated more asexually and reproduced by spreading its rhizomes (Zhao *et al*., 2022).

In particular, some problems should be mentioned, the most notable examples are an increase in the prices of energy in the world, and the limitation of fossil resources and fuels, and the high annual growth of energy consumption in Iran, and elimination of energy subsidies and mainly technical and economic inefficiency of energy consumption in most industries, because the energy consumption of management and energy efficiency improvement are an absolute necessity (Ali Kaab e*t al.*, 2019a). The more significant emission of greenhouse gases that lead to global warming is the most severe problem and the greatest threat to humanity today. In addition, consumers in developed countries want to use high-quality, healthy food with minimal side effects on the environment (Mostashari-Rad *et al*., 2021). Also, because nowadays, agricultural and food industries prefer to increase their production, it is generally based on limited resources such as fossil fuels, water resources, and other non-renewable resources. Nevertheless, the earth is currently facing a lot of environmental concerns. Environmental problems such as water, soil, air pollution, depletion of resources, soil erosion, and soil fertility decline (Taherzadeh-Shalmaei *et al*., 2021). However, governments need technologies that save energy and reduce their costs and increase their profits (cost savings); particularly in more recent decades, countries reconsider their energy policies. Therefore, most countries research environmental resources and problems, and the goal of industrial systems is to analyze, improve design, and enhance the activity of systems capabilities (Payandeh *et al*., 2021).

This study aims to examine trends in input and output energy on agricultural systems to optimize energy consumption and reduce operation and production costs by reducing energy costs. The growth of the world population and energy constraints that cause access to sufficient energy in the future will be more difficult in many ways (Eskandari and Attar, 2015). It is also predicted that there is potential for more growth in Third World countries because of the young population. The population will grow in the coming years, and the entry of new generations into the labor market and market economies in developing countries will increasingly lead to demand for goods, services, and energy. In addition, the demand for food is expected to grow because of population growth, and it will be essential to access safe, sufficient, nutritious, and quality food and improve food security worldwide. It is necessary to pay sufficient attention to conserving biodiversity and the environment simultaneously (Mousavi-Avval *et al*., 2011). Agriculture as a producer and consumer of energy consumes considerable commercial and non-commercial energy directly and indirectly (Akdemir *et al*., 2012). All agricultural systems, from simple types in traditional agriculture to intensive and modern farming systems that all these need the consumption of energy like human power and what is provided by the sun. Because high energy consumption is used in agriculture and food production, but to stabilize energy production, excess energy is injected into the food production industry. There are different systems related to energy among the history of agriculture (Amezcua-Allieri *et al*., 2019).

Pre-industrial systems operated with low consumption of input energy and labor, resulting in limited output. During the era of semi-industrial agriculture, there was a notable increase in agricultural input, energy consumption, and labor demand. Complementary energies like draft animals were employed to assist in work, substituting farm labor and human resources. The industrial agriculture phase, characterized by intensive agriculture, witnessed peak consumption of inputs such as fossil fuels, machinery, and equipment. Human resources played a significant role in various operations during this period.

Knowledge of energy consumption in any production operation is a valuable method for calculating energy. It is essential to determine and analyze the sectors and areas using high energy, which can be determined only by analyzing the amount of energy consumed in production operations. Analysis of energy allows the unit of production to compare existing operations with new production methods and even modify production lines (Pahlavan *et al*., 2012). Energy analysis in agriculture has a significant role in the human development approach to agricultural ecosystems. Therefore this improves the quality of decisions and plans in the management and development of the agricultural sector (Longo *et al*., 2017). Although energy analysis cannot provide a complete understanding of the agricultural ecosystem, the human development approach to the agricultural ecosystem can effectively improve development decisions and plans (Awani *et al*., 2017).

All the methods that humans use to increase the efficiency of stabilization energy, use energy subsidies. Energy consumption is used directly and indirectly. Direct energy resources include planting, holding, harvesting, and indirectly energy resources include production of inputs such as pesticides, chemical fertilizers and machinery, storage and drying of crops, and other input related to crop production. In recent years, life cycle assessment (LCA) has become a suitable tool to study and determine the impact of environmental impact on agricultural and food production. In many countries, it is used as a tool for macro-planning decisions. LCA is a way to determine all the environmental impacts associated with a product, process, or service and all pollutants released and wastes released into nature (Dorr *et al*., 2021). During the last century, this method was primarily used in industrial fields, but today, most researchers use it extensively to determine the impact of products, processes, and services on the environment (Cellura *et al*., 2012). While LCA has seen greater utilization in agriculture compared to industry, there is a lack of comprehensive studies on crop analysis involving crops like wheat, sugar beet, and corn, as well as the overall environmental impacts of these crops (Ingwersen, 2012). LCA involves assessing the environmental aspects and potential consequences, including resource use and environmental impacts throughout the entire life cycle of a product—from raw material extraction, through production and use, to recycling and final disposal (known as Cradle to Grave) (Ghasemi-Mobtaker *et al*., 2020).

The energy of agricultural products for the production of raw materials in the food industry can be divided into two main groups: direct energy and indirect energy (Kaab *et al*., 2019a). Direct energy is gained from the energy of fossil fuels or a source of renewable energy such as biofuels, which are used directly in processes. In today's world and developed countries, direct energy consumption comes from a fossil fuel source such as diesel fuel, gasoline, liquefied petroleum gas, coal, and electricity; however, fossil fuels or other energy sources are used in its production (Kitani, 1999). In non-mechanized farming (Uncompact) such as garden thyme and peppermint, different forms of fossil energy, human and animal labor have the most extensive share direct energy input of the system. Indirect energy is a type of energy used to produce input (before farming). Indirect energy is used to produce machines, fertilizers and chemical input, seeds, and organic fertilizers. Generally, indirect energy is used for the energy consumption of fertilizers, especially nitrogen fertilizers. Other essential items of indirect energy consumption include agricultural machinery, pesticides, and field irrigation (Payandeh *et al*., 2021). Energy analysis in various agricultural ecosystems shows that the most indirect energy in farms is primarily related to nitrogen fertilizer (20 to 30% of total energy) and secondly related to machinery (6 to 12% of total input energy) (Nabavi-Pelesaraei *et al*., 2022).

Undoubtedly, reducing the dependence of systems on input and energy consumption and increasing energy efficiency are the main goals in all agricultural ecosystems. The study of energy efficiency would mean comparing the energy consumption of input and the energy of the agricultural system (output energy) (Khoshnevisan *et al*., 2014). Agricultural experts have always considered it because energy subsidies are given in the country. Farmers pay unrealistic prices for energy; in other words, the study of energy efficiency has not received more attention in recent years. Evaluation of systems based on energy consumption patterns has this advantage over economic evaluation, independent of time, region, and country. Results obtained from energy analysis are quantitative. In addition, these have high-quality qualitative concepts. Therefore, an equivalent method of consuming input and products as energy is used in various production systems today. However, analysis of energy is done in any production system because the plan of effective energy consumption is to be considered to increase revenue or reduce costs (Khorasanizadeh *et al*., 2014). The total energy content of input consumed during the production process is called the input energy for a production system. The output energy is also called the total energy of the products generated in the same production system. Energy efficiency or energy ratio is calculated by dividing output energy and input energy (Keyes *et al*., 2015).

Abeliotis *et al*. (2013) an analysis was conducted on the life cycles of various types of beans in Greece. The findings indicated that when assessments were made on the basis of the amount of material produced per kilogram, bean varieties that demanded increased inputs and generated higher yields. Cellura *et al*. (2012) examined the life cycle of several greenhouse crops, including peppers, watermelons, and tomatoes in Italy. Their study included the stages of raw material extraction, input production, product production, transportation, and packaging. Their evaluation showed that most of the pollutants depend on two factors: the type of packaging and the structure of greenhouses. In addition, greenhouses that did not require a heating system had better environmental effects. On the one hand, trade is global (the globalization of trade). On the other, increasing environmental pollution caused by excessive consumption of agricultural input subsidies, which input subsidies have adverse effects on the environment because of the inexpensive cost of their production, and overproduction of subsidies also results in unintended environmental harms. It is necessary to create policies and procedures. Targeted subsidies and the elimination of subsidies are the most important economic policies; these policies will increase the price of energy input. Therefore, there is an increase in the cost of agricultural products that it causes likely to increase pressure on agricultural sectors. It is necessary to do more research on this subject. In this regard, this study has been done to evaluate the energy efficiency in the cultivation of garden thyme and peppermint as a sample of low-input farming systems. Considering that in the last decade, we are facing a decrease in natural resources due to population growth, and on the other hand, we have witnessed a change in the agricultural pattern and more reliance of this industry on chemical fertilizers, and pesticides. significant changes in the energy consumption pattern in the agricultural sector, which has become more dependent on fossil fuels.

The novelty of this study lies in its approach to evaluating the efficiency of energy use in the cultivation of medicinal plants, specifically garden thyme and peppermint. By employing a combination of LCA and support vector machine (SVM) modeling, the researchers are able to provide a comprehensive analysis of the energy efficiency throughout the entire life cycle of these plants, from cultivation to processing. Using LCA allows researchers to assess the environmental impact of energy use at each stage of the plant's life cycle, providing valuable insights into areas where efficiency improvements can be made. Integrating SVM modeling further enhances the study by enabling the prediction of energy use patterns and identifying key factors that influence efficiency in cultivation. Overall, this approach offers a novel and holistic perspective on the energy use efficiency in the cultivation of medicinal plants, providing valuable information for sustainable practices in agriculture and potentially guiding future research and developments in this field. To achieve sustainable agriculture in the country, the implementation of energy consumption management policies along with production management can be a way forward. On the other hand, predicting the energy content of inputs and outputs in the production of garden thyme and peppermint products along with the prediction of the energy output of these plants can be considered an important step in the production industry of these products. Therefore, in the present research, the energy output values of garden thyme and peppermint products have been predicted using a SVM. Also, using standard evaluation criteria, the performance of the SVM in estimating the output energy of these products has been checked.

Materials and Methods

Data calculated

The data needed to estimate the energy output includes 240 data series, which were selected from the statistical population of 480 people (from Tehran, Alborz, and Qazvin provinces of Iran), and the data was obtained through interviews with producers and specialists in the field of garden thyme and peppermint plants. The location of the case study is depicted in Figure 1. The independent variables of this research for garden thyme and peppermint include labor force, machines and tools, diesel fuel, fungicide, nitrogen fertilizer, water for irrigation, electricity, seedlings for garden thyme, and rhizome for peppermint. The dependent variable and the purpose of prediction is the output energy, which was obtained based on the answers of the interviewees, and after training the SVM network, the output energy was predicted based on the inputs and outputs (Ministry of Agriculture Jihad, 2021).

Fifty-five copies of these questionnaires were completed for this research. The information indicated that more than 93% of garden thyme and peppermint cultivation operations were done entirely manually and traditionally. So in this estimate, only man and animal power are included to prepare land operations and cultivate garden thyme and peppermint. It is notable that garden thyme and peppermint are cultivated in small patches across various regions, with the largest patch spanning several hundred square meters. Due to the fact, this unit is various in different parts in research of study area, and the average area under cultivation of garden thyme and peppermint was about (1000 square meters) for each farmer. So each area refers to metric units divided into hectare units, and calculations have been done.

There are various methods to determine the sample size, one of the most used formulas for determining the sample size is Cochran's formula. In this method, the sample volume is calculated with the error level of 5% with the following formula (1) (Cochran, 1977):

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

where N is the population size. The p statistic is the percentage distribution of the trait in the society. The q statistic is also the percentage of people who do not have the trait under study. If the amount of p and q is not known, use their maximum value, i.e. 0.5. At the 5% error level, the value of z is equal to 1.96 and Z^2 is equal to 3.84. Factor d is the difference between the real ratio of the trait and the amount estimated by the researcher. The accuracy of sampling depends on this factor, and if the sampling has the highest accuracy, the maximum d value equal to 0.05 is used.

Energy indicators

Agricultural operations in garden thyme and peppermint include plowing, disc, leveling, fertilizing (animal and chemical fertilizers) and planting, weed control, irrigation, transportation, and harvesting in the first year and agricultural operations are such as fertilizing, weed control, irrigation, and harvesting cleaning leaves, and transportation in the second to fourth years. The energy consumption is calculated in each case, producing energy and consumption energy are compared finally. Energy consumption was divided into direct and indirect energy consumption. Human resources energy and energy required for irrigation are considered in the section of direct energy consumption. The energy required seedling preparation, chemical fertilizers (nitrogen and phosphate fertilizers) in indirect energy consumption (Ojaghlou *et al.*, 2023). Therefore, two questionnaires were prepared, one related to garden thyme and the other related to peppermint. In each form, questions were asked about direct and indirect input energy in cultivating garden thyme and peppermint. The data was collected by questionnaires that focused on sections such as plowing, disc, land leveler, conducting aqueduct, chemical, and livestock fertilizers, weeding and chemical pesticides, irrigation, fertilizing and harvesting operations in the first year, and sections such as fertilizers, weeding, and spraying, irrigation, fertilization, and harvesting were considered for the second to fourth year.

The input was used to study products, including labor, machinery (tractors and other farm machinery), diesel fuel, irrigation water, electricity, chemical toxins (herbicides, insecticides, and fungicides), seedlings, and rhizomes. The input-output model involved thyme and peppermint. However, the energy balance coefficients were used to determine the amount of energy equivalent to input and input-output. Energy coefficients for input and input-output are presented in Table 1. Therefore, the energy equivalent of each input is obtained by multiplying the consumption of each input by the specific energy of input according to the following relation (Eq. 2) (Eskandari and Attar, 2015).

$$E_{input} = I_{consumption}\ ec_{input} \qquad \text{(Eq. 2)}$$

That input the energy is equivalent to the consumption of input to MJ consumption and the amount of consumption of input is (human labour, fossil fuels, electricity, *etc.*) at the unit of that and input the energy content of input at MJ.

Figure 1. Location of the studied area.

Life cycle assessment

In a LCA, all the production processes involved in creating a product, from raw material extraction to waste disposal after consumption (cradle to grave), are analyzed to minimize their environmental impact (Figure 2). Each LCA consists of four essential steps (Samuel-Fitwi *et al*., 2013): i) definition of purpose and scope involves establishing the general framework of work, including functional units (reference streams), system boundaries, resource allocation, and selection of parts of the work; ii) inventory analysis entails considering the sources used and the release of pollutants in the whole or part of the product lifecycle, as determined by the system's boundaries; iii) evaluating the effects of the life cycle involves summarizing and presenting the release of essential pollutants in the practical sections to interpret the results; iv) analysis of results encompasses analyzing all results to draw conclusions and provide solutions.

Impact categories used in this study are shown in Table 2. The environmental impact assessment method has been selected based on CML 2 baseline method (Di Maria *et al.*, 2016).

In LCA, off-farm emissions comprise various inputs including human labor, electricity, water, seeds, biocides, chemical fertilizers, diesel fuel, and machinery. On the other hand, On-Farm emissions are associated with agricultural machinery like tractors and trailers used for farm operations. Data from Tables 3 to 5 are used to evaluate emissions from machinery usage, diesel fuel combustion, and chemical fertilizer application. Maintaining clean fuel properly is critical for optimal performance, as mishandling can lead to fuel contamination, resulting in pollutants such as water, dust particles, and microbial growth, potentially causing issues like black sludge. Thus, ensuring fuel quality is vital for efficient operation, prolonged service life, and adherence to emission regulations in engines (Soam *et al*., 2017). The production of strategic crops relies heavily on rice fertilizer, which plays a crucial role in improving crop yields. However, excessive fertilizer usage can led to negative consequences such as decreased yields and increased environmental emissions. Chemical fertilizers can negatively impact air and water quality by releasing greenhouse gases and heavy metals into the soil. To evaluate the magnitude of these environmental emissions, the coefficients of the input consumption values are multiplied, as discussed in the research findings of (Mostashari-Rad *et al*., 2021).

Table 1. Content of input-output in production of plants.

Inputs	Unit (MJ unit^{-1})	Energy content	Reference
Human labour	hr	1.96	(Kitani, 1999)
Machines and Equipment	kg		
Tractor	hr	9-10	(Kaab *et al.*, 2019)
Diesel fuel	L	47.8	(Taghinezhad *et al.*, 2014)
Chemical pesticides	kg	120	(Salehi *et al.*, 2014)
Fertilizer	kg		
Nitrogen	kg	78.1	(Kitani, 1999)
Phosphorus	kg	17.4	(Kitani, 1999)
Pottassium	kg	13.7	(Kitani, 1999)
Animal manuer	kg	0.3	(Kitani, 1999)
Water of irrigation	m^3	1.02	(Ren *et al.*, 2012)
Electricity	kWh	12	(Kaab *et al.*, 2019b)
Seedling	kg	0.28	(Hedau *et al.*, 2014)
Rhizom	kg	0.5	(Hedau *et al.*, 2014)
Outputs	kg		
Garden thym		10	(Hedau *et al.*, 2014)
Peppermint		10	(Hedau *et al.*, 2014)

Table 2. Sections of the work and units of the size of each section.

Impact categories	Symbol	Measurement units
Abiotic depletion	AD	kg Sb eq.
Acidification potential	AC	kg SO^2 eq.
Eutrophication potential	EU	kg PO_4^{-2} eq.
Global warming potential	GW	kg CO_2 eq.
Ozone layer depletion	OD	kg CFC-11 eq.
Human toxicity potential	HTP	kg 1,4-DCB eq.b
Freshwater aquatic ecotoxicity	FAET	kg 1,4-DCB eq.b
Marine aquatic ecotoxicity	MAET	kg 1,4-DCB eq.b
Eutrophication potential	TE	kg 1,4-DCB eq.b

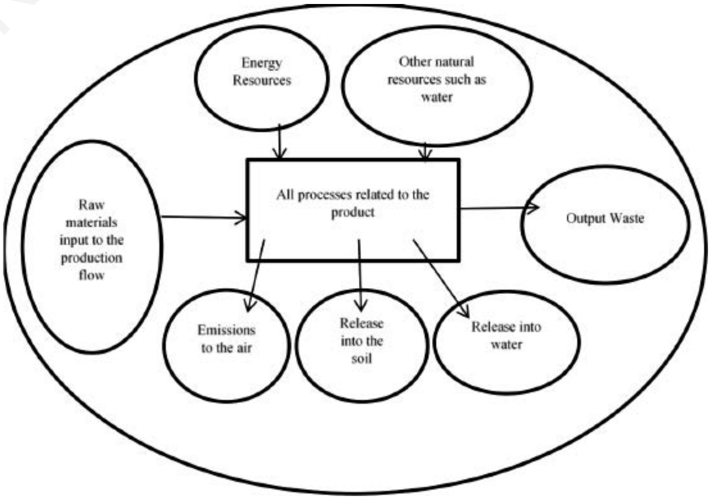


Figure 2. The life cycle of a production process.

In order to obtain the required information, the Ecoinvent database was used. Simapro 9.5.0.1 version software has also been used to perform life cycle evaluation calculations.

Support vector machine algorithm

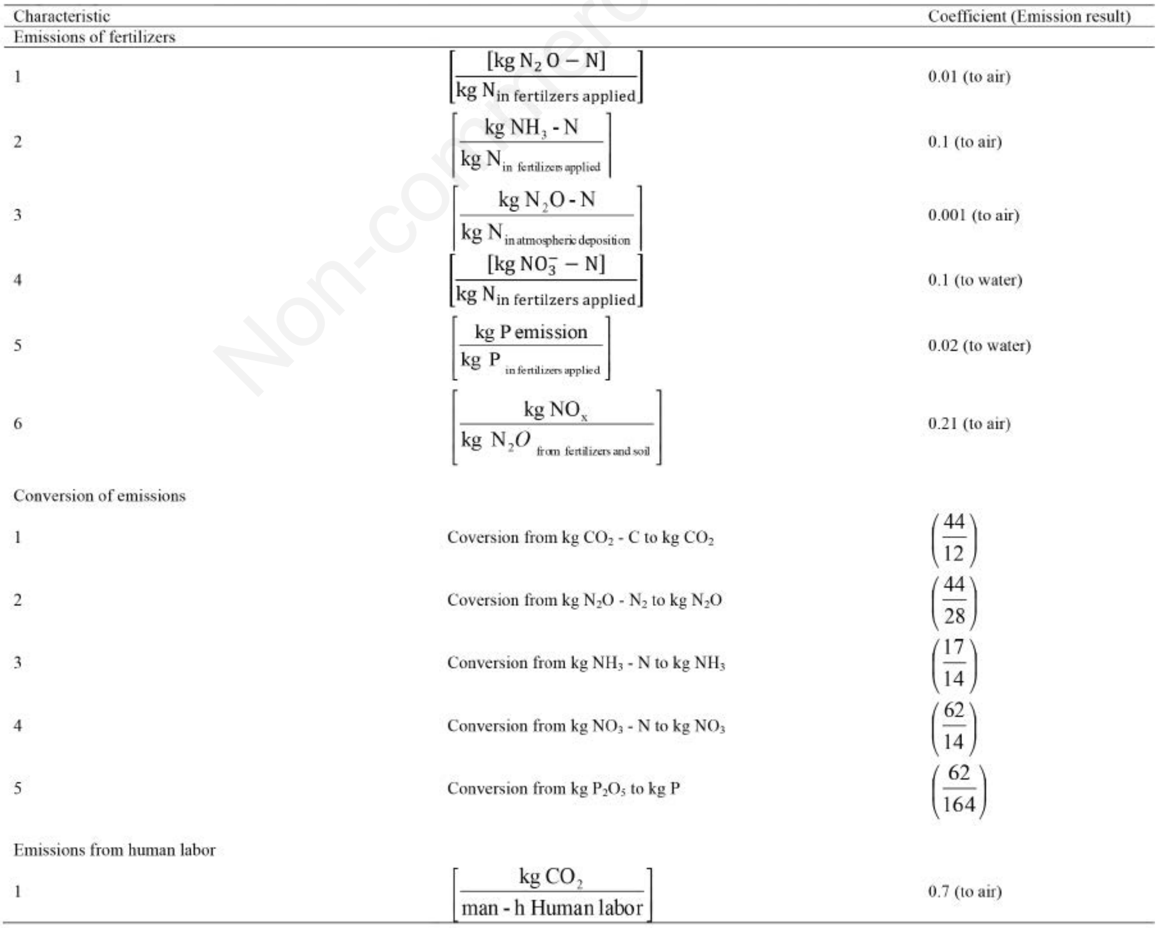
The SVM algorithm is a type of data mining algorithm that has various applications such as data classification and prediction. SVM is one of the supervised learning methods, which was first generalized by Vapnik for nonlinear mode. This algorithm uses the regression method in the field of solving classification and prediction problems, and like artificial neural networks, the problem-solving steps are divided into two steps: training (Train) and testing (Huang et al., 2002). The basis of SVM work is the linear classification of data, and it is tried to consider a line that has a high confidence margin in the linear division of data. The theory of SVM is the classification and linear separation of data. If the data is linear, in order to separate them, try to select a page with the maximum margin (Figure 3) (Kalantary *et al*., 2020).

The working steps of the SVM are as follows: i) entering dependent and independent data series into the statistical software environment; ii) Identification of dependent and independent parameters by statistical software; iii) Prediction of dependent parameter based on independent parameters.

Table 3. Equivalent of direct emission of 1 MJ diesel fuel for 1 MJ burning in EcoInvent database.

Emission	Amount (g MJ^{-1} diesel)
CO_2	74.5
SO_2	2.41E-02
CH_4	3.08E-03
Benzene	1.74E-04
Cd	2.39E-07
Cr	1.19E-06
Cu	4.06E-05
N_2O	2.86E-03
Ni	1.67E-06
Zn	2.39E-05
Benzo (a) pyrene	7.16E-07
NH_3	4.77E-04
Se	2.39E-07
PAH	7.85E-05
HC, as NMVOC	6.80E-02
NOx	1.06
CO	1.50E-01
Particulates (b2.5 μm)	1.07E-01

Table 4. Coefficients for calculating the on-farm emissions related to application of inputs in paddy production (IPCC, 2006).



Characteristic		Coefficient (Emission result)
Emissions of fertilizers		
1	$\left[\frac{[\text{kg } N_2O - N]}{\text{kg } N_{\text{in fertilzers applied}}}\right]$	0.01 (to air)
2	$\left[\frac{\text{kg } NH_3 \text{ - } N}{\text{kg } N_{\text{in fertilizers applied}}}\right]$	0.1 (to air)
3	$\left[\frac{\text{kg } N_2O \text{ - } N}{\text{kg } N_{\text{in atmospheric deposition}}}\right]$	0.001 (to air)
4	$\left[\frac{[\text{kg } NO_3^- - N]}{\text{kg } N_{\text{in fertilzers applied}}}\right]$	0.1 (to water)
5	$\left[\frac{\text{kg P emission}}{\text{kg } P_{\text{in fertilizers applied}}}\right]$	0.02 (to water)
6	$\left[\frac{\text{kg } NO_x}{\text{kg } N_2O_{\text{ from fertilizers and soil}}}\right]$	0.21 (to air)
Conversion of emissions		
1	Coversion from kg CO_2 - C to kg CO_2	$\left(\frac{44}{12}\right)$
2	Coversion from kg N_2O - N_2 to kg N_2O	$\left(\frac{44}{28}\right)$
3	Conversion from kg NH_3 - N to kg NH_3	$\left(\frac{17}{14}\right)$
4	Conversion from kg NO_3 - N to kg NO_3	$\left(\frac{62}{14}\right)$
5	Conversion from kg P_2O_5 to kg P	$\left(\frac{62}{164}\right)$
Emissions from human labor		
1	$\left[\frac{\text{kg } CO_2}{\text{man - h Human labor}}\right]$	0.7 (to air)

Evaluation criteria

In this research, three evaluation criteria have been used to compare the results of output energy prediction models, which are presented in the form of the Eqs. (3) to (5). Errors and NRMSE is the normalized root mean square error. In the following relationships, the Pre index is related to the predicted values, and the Obs index is related to the actual model values. It is necessary to explain that the best model is the model in which RMSE tends to zero and R^2 to one and NRMSE values are less than ten percent (Kaab *et al.*, 2019a).

$$R^2 = \left(\frac{n\sum X_{Obs} X_{Pre} - (\sum X_{Obs})(\sum X_{Pre})}{\sqrt{n(\sum X_{Obs}^2) - (\sum X_{Obs})^2}\sqrt{n(\sum X_{Pre}^2) - (\sum X_{Pre})^2}} \right)^2 \quad \text{(Eq. 3)}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{1}^{n}\left(X_{Obs} - X_{Pre}\right)^2} \quad \text{(Eq. 4)}$$

$$NRMSE(\%) = \frac{RMSE}{\sum_{1}^{n} X_{Obs}} \times 100 \quad \text{(Eq. 5)}$$

Results and Discussion

Energy analysis

The results of input and output energy of medicinal plants presented in Table 6. Moreover, some operations are done with manpower. These operations include plowing, soil leveling, transportation, and distribution of chemical and animal fertilizer, transportation and planting of seedlings (garden thyme) and rhizomes (peppermint), conducting aqueduct for irrigation of farms, irrigation operation, and harvesting leaves in last year, and 1.96 MJ ha^{-1} is consumed for the energy of worker (Kitani, 1999). Fertilizers and chemical pesticides are the most important agricultural input that significantly affects agricultural functions, and often these are nitrogen and phosphorus fertilizers. Therefore, to calculate the energy of chemical fertilizers (energy required for production) in this study, the average consumption of these two types of fertilizers was considered in the study areas.

The information obtained from the completed questionnaires is based on farmers' statements and available resources. The average yield of garden thyme is about 6 tons of leaves sold at the end of the farm operation period. Also, since peppermint is a perennial plant, the use of this plant in a plot of land will not be economical for more than three years. In the first year, the highest weight and economic yield of fresh peppermint were obtained from the integrated nutrition system at a rate of 12 tons per hectare. However,

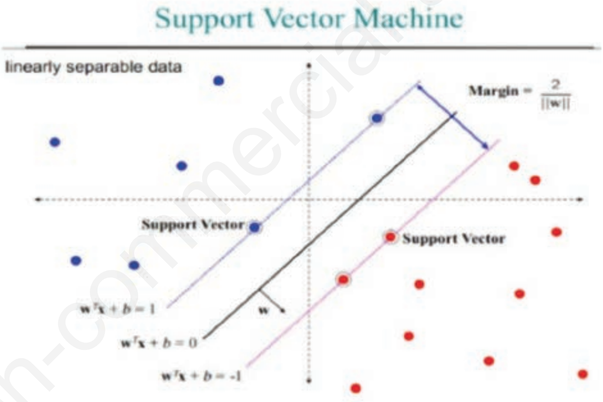


Figure 3. Support vector machine.

Table 5. Coefficients for calculating the On-Farm emissions to soil of heavy metal related to application of chemical fertilizers in paddy production (IPCC, 2006).

Characteristic		Heavy metals							
		Cd	Cu	Zn	Pb	Ni	Ni	Cr	Hg
1	$\left[\frac{\text{mg Heavy metal}}{kg\ N_{in\ fertilzer\ applied}}\right]$	6	26	203	5409	20.9	20.9	77.9	0.1
2	$\left[\frac{\text{mg Heavy metal}}{kg\ P_{in\ fertilzer\ applied}}\right]$	90.5	207	1923	154	202	202	1245	0.7
3	$\left[\frac{\text{mg Heavy metal}}{kg\ K_{in\ fertilzer\ applied}}\right]$	0.2	8.7	11.3	1.5	4.5	4.5	10.5	0.1

growing plant age in the second year caused fresh weight yield to a 15% decline.

Based on the obtained results, different types of energy and the share of each energy consumption in the production of thyme and peppermint are shown in Table 7. This table shows that in the production of thyme and peppermint, about 90% of energy consumption is non-renewable. Only 10% of energy is renewable energy, the share of direct and indirect energy is equal to 42 and 58%, respectively. First, a significant portion of energy consumption is related to diesel fuel. A large part of this fuel is related to tractor consumption for operation and energy used for irrigation. It is vital to save diesel fuel. It can be done by managing farms and modernizing machines, drawing the primary map of the newly constructed farms to coordinate with modern machines, managing pesticides, chemical fertilizers, and modernizing irrigation systems. Secondly, it is essential to pay attention to renewable energy in this region, and it should be given priority. For example, biofertilizers such as manure and green manure and renewable fuels such as biodiesel can increase the share of renewable energy in total energy consumption in the agricultural sector. As it is known, the amount of output energy in one hectare of garden thyme and peppermint is equal to 260 thousand megajoules per hectare and 235 thousand MJ per hectare in the 4-year period of garden thyme and peppermint old which this amount of energy obtained from the percentage of each material and the yield of different parts of garden thyme and peppermint, that the highest share of energy consumption of input is related to electricity (Figures 4 and 5). Energy indices in production showed in Table 8. The total ratio of energy production to consumption energy in four years is 2.2 and 2.17 in garden thyme and peppermint farm, respectively, that these are comparable with garden plants such as apples (0.53), oranges (0.370, tomatoes 0.6), and spinach (0.23) in the United States (Koocheki and Hosseini,1994). There are several significant differences that the most input energy to these farms mainly depends on fossil fuels and machinery in the United States. However, the most input energy in the cultivation garden thyme and peppermint relates the electricity and chemical fertilizers in Iran, which is in line with sustainable agriculture. The use of machinery in the production of garden thyme and peppermint will cause a sharp decline in energy efficiency because of fossil fuel energy density.

As can be seen in the production of medicinal plants, the largest share of energy consumption has been used in energy-related chemical fertilizers and electricity, with a considerable difference compared to other inputs. Seedlings propagate garden thyme; the electrical energy consumption of garden thyme is relatively higher than the electricity consumption of peppermint. It can be considered because it takes a longer time to plant and harvest seedlings, and the plant needs a considerable amount of water. Much electricity is consumed in the cultivation of garden thyme. Also, more work is needed to cultivate thyme seedlings, which has increased work consumption because many workers have to effort on the farm. The research found that the energy ratio of two products was higher than one, which shows that the cultivation of plants is cost-effective in the country's agriculture. High input-output is a good reason for better managing crop input because these plants are perennial.

Life cycle assessment analysis

In order to evaluate the cultivation environment of the two studied crops, the life cycle of these crops from the stage of raw material extraction to harvest in the field was studied. Comparisons are made based on two different functional units. In the first stage, all calculations are based on one ton of product produced on the farm. In other words, the functional unit has been selected as one ton of product produced. After that, a general comparison between the two crops in terms of pollution produced per hectare has been made.

As can be seen in Table 9, thyme produces more environmental loads than peppermint. The results show that the highest pollution levels are related to the four indicators of AD, HTP, GW, and MAET. Natural gas and electricity in the production to consumption phase have shown the most significant impact on emissions. The share of electricity in the global warming index is significantly higher than in natural gas. The evaluation of the cultivation environment for thyme and peppermint through a LCA provides a comprehensive understanding of the environmental impacts associated with both crops. By analyzing the life cycle from raw material extraction to harvest, the assessment generates insights into how cultivation practices affect sustainability. Using one ton of product

Table 6. The amont of input and output energy of studied medicinal plants.

	Input-output energy (MJ ha^{-1}) Garden thyme	Peppermint
Inputs		
Human labour	3450	2730
Machines and equipment	885	885
Diesel fuel	4150	3880
Gasoline fuel	256.5	260
Fugicides	1329	1310
Herbicides	365	385
Insecticides	381	481
Nitrogen fertilizer	38,256	35,482
Phosphorus fertilizer	8549	8500
Pottassium fertilizer	2561	2561
Animal manuer	8750	8750
Water of irrigation	3680	3550
Electricity	44,320	38,650
Seedling	1280	-
Rhizome	-	860
Outputs		
Garden thym	260,000	-
Peppermint	-	235,000

Table 7. Classification kinds of energy in the production of study.

Items	Amount to per hectare (MJ ha^{-1}) Garden thyme	Peppermint
Renewable energy	12,200	11,480
Non-renewable energy	105,847	96,750
Direct energy	51,920	45,520
Indirect energy	66,127	62,710

Table 8. Energy indices in production of the study.

		Garden thyme	Peppermint
Total input energy	MJ ha^{-1}	118,047	108,230
Total output energy	MJ ha^{-1}	260,000	235,000
Energy ratio	-----	2.20	2.17
Energy productivity	Kg MJ^{-1}	0.05	0.11
Energy intensity	MJ Kg^{-1}	19.67	9.02
Net energy	MJ ha^{-1}	141,953	126,770

produced as the functional unit allows for a standardized comparison between the two crops. This method helps aggregate various environmental impacts into a single metric, making it easier to identify which crop has a greater ecological footprint or is more efficient in its resource use. The indicators mentioned AD, HTP, GW, and MAET represent different aspects of environmental loads.

AD. This indicator measures the potential of substances to cause acid rain, which can harm ecosystems, water bodies, and soil health. The higher AD associated with thyme suggests that its cultivation may release more nitrogen oxides or sulfur dioxide, leading to greater acidification.

HTP. This assesses the potential of pollutants to cause health impacts on humans. If thyme ranks higher than peppermint in this category, it may indicate that the chemicals used in its cultivation or the emissions it generates pose a greater risk to human health.

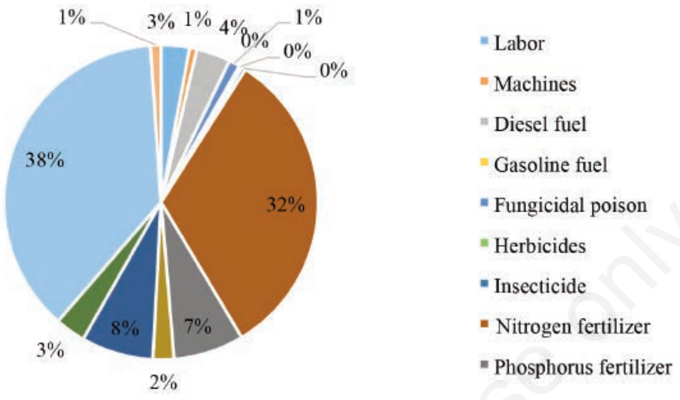


Figure 4. The share of energy consumption of various input in garden thyme production.

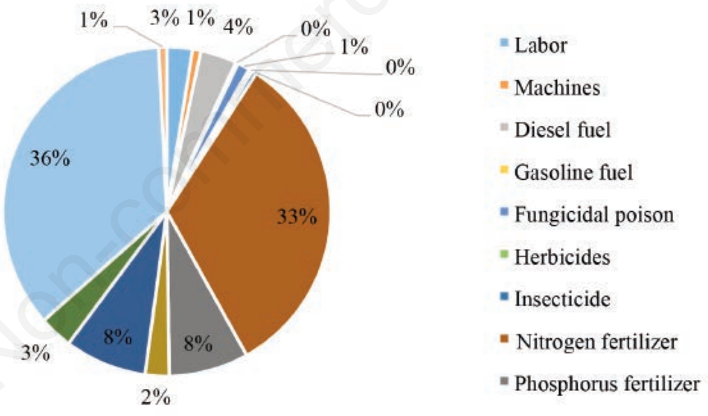


Figure 5. The share of energy consumption of various input of peppermint production.

Table 9. Environmental indicators in the cultivation of two studied medicinal plants per ton of product.

Impact categories	Measurement units	Garden thyme	Peppered mint
AD	kg Sb eq.	2.15	2.26
AC	kg SO$_2$ eq.	0.438	0.389
EU	kg PO$_4$ eq.	0.0723	0.0454
GW	kg CO$_2$ eq.	118	105
OD	kg CFC-11 eq.	0.0000281	0.0000251
HTP	kg 1,4-DCB eq.^{b}	42.2	32.5
FAET	kg 1,4-DCB eq.^{b}	6.1	5.75
MAET	kg 1,4-DCB eq.^{b}	18456	14325
TE	kg 1,4-DCB eq.^{b}	0.288	0.231

GW. This is particularly relevant in discussions of climate change. The finding that thyme has a higher GW impact suggests that its production may lead to increased greenhouse gas emissions compared to peppermint.

MAET. This highlights the impact on marine biomes. If thyme exhibits a greater MAET score, it might be linked to runoff from agricultural practices that negatively affects aquatic ecosystems.

The analysis points to natural gas and electricity as significant contributors to environmental emissions during the production and consumption phases. The finding that electricity has a more substantial impact on global warming emphasizes the energy mix used in production systems. If the electricity consumed is generated from fossil fuels, it could explain the high emissions. On the other hand, a cleaner electricity grid could potentially reduce the overall environmental impact of thyme production. From the results presented in Table 9, it is evident that thyme's higher environmental loads suggest that its cultivation may need more attention when considering sustainable agricultural practices. This analysis can lead to the following considerations.

Cultivation practices. Implementing more eco-friendly farming practices, like using integrated pest management (IPM), organic fertilizers, or renewable energy sources, could potentially mitigate the impacts observed.

Crop selection. For farmers or consumers concerned about environmental sustainability, choosing peppermint over thyme might be advisable based on the pollution produced per hectare and more favorable sustainability metrics.

Policy implications. Understanding the environmental profiles of these crops could influence agriculture policies, encouraging practices that reduce emissions, improve energy efficiency, and promote sustainable development.

In conclusion, the detailed assessment reveals critical insights into the life cycle impacts of thyme and peppermint, highlighting the importance of energy sources and cultivation practices in shaping their environmental footprints. Further research might be necessary to delve deeper into specific factors contributing to the differences observed and to identify improvement opportunities.

In a study evaluating the environmental impact of rose cultivation in Ethiopian greenhouses, it was reported that most of the pollution in all parts of the work was due to the production and use of chemical fertilizers (Sahle and Potting, 2013). Other studies have evaluated greenhouse crops in terms of emissions. A study on greenhouse gas emissions in Sweden found that for every 42 GJ of energy consumed in these greenhouses, 3300 kg of equivalent carbon dioxide would be emitted (Carlsson *et al*., 2012). Clarke *et al*. (2019) In their study determining environmental loads and resources used in crop and horticulture, noted that about 97% of the energy used to produce greenhouse tomatoes was used for heating and lighting. In addition, they showed that producing every 1000 kg of tomatoes requires 125 GJ of energy, and consequently, 9400 kg of average carbon dioxide will be released. Of course, it should be noted that the difference between the results of these studies and the above study is due to differences in the cultivation methods used and the choice of different boundaries to review the results.

Support vector machine model analysis

In this research, the SVM model was used to estimate the output energy of medicinal plants of garden thyme and peppermint. For this purpose, independent parameters were used to model and estimate the energy output, which includes labor force, machines and tools, diesel fuel, fungicide, nitrogen fertilizer, water for irrigation, electricity, seedlings for garden thyme, and rhizome for peppermint. The total number of data used in the research includes 240 data series, 75% of the total available data (180 data) were considered for training the network and the remaining 25% of the data (60 data) were used for network testing. Considering that the values of the output energy and the independent parameters of the current research were large numbers, for better display and understanding in the graphs, the figures of all the data were divided by the number 104, and their ranges are presented in Tables 10 and 11.

The selection of data for the training and test period was done by the software itself and randomly. To have the least error during the process of predicting the results, the training process was done with several repetitions. The results of the SVM along with the evaluation criteria are presented in Table 12, where it can be seen that the SVM has high accuracy in estimating the output energy. Thus, the evaluation criteria for the garden thyme plant for the test

Table 10. Range of independent and dependent data for garden thyme plant.

Parameters	Labor force	Machines and tools	Diesel fuel	Fungicide	Nitrogen fertilizer	Water for irrigation	Electricity	Seedlings	Energy output
min	0.331×10^4	0.072×10^4	0.389×10^4	0.118×10^4	3.721×10^4	0.355×10^4	4.36×10^4	0.12×10^4	21.1×10^4
max	0.354×10^4	0.102×10^4	0.439×10^4	0.145×10^4	4.113×10^4	0.39×10^4	4.54×10^4	0.13×10^4	22.3×10^4

Table 11. Range of independent and dependent data for peppermint plant.

Parameters	Labor force	Machines and tools	Diesel fuel	Fungicide	Nitrogen fertilizer	Water for irrigation	Electricity	Seedlings	Energy output
min	0.264×10^4	0.072×10^4	0.379×10^4	0.119×10^4	3.421×10^4	0.348×10^4	3.699×10^4	0.078×10^4	18.33
max	0.284×10^4	0.096×10^4	0.401×10^4	0.144×10^4	3.824×10^4	0.362×10^4	3.999×10^4	0.094×10^4	19.79

Table 12. Support vector machine prediction results for garden thyme and peppermint plants.

		Training			Testing	
Model	R^2	RMSE	NRMSE%	R^2	RMSE	NRMSE%
Garden thyme	0.9823	0.0332	0.1533	0.9796	0.0367	0.1695
Peppermint	0.9833	0.0357	0.1876	0.9765	0.0481	0.251

period are equal to R^2=0.9796, RMSE=0.0367, and NRMSE=0.1695, and these criteria for the peppermint plant are equal to R^2=0.9765, RMSE=0.0081, and NRMSE=0.0081.

By examining the error values, it can be seen that garden thyme has far less error than peppermint and the only difference between the two is in the presence of seedling and rhizomes, which indicates the effect of seedling on thyme along with other parameters. The values of the normalized root mean square error in the present research for both plants are below 1%, which completely simulates and predicts the real conditions, which shows the very favorable performance of the SVM algorithm. Figure 6 shows the distribution curve of real and predicted data in the test and training phase for garden thyme and peppermint. According to the figure, it can be seen that the network training has a high evaluation, which indicates the high accuracy of the SVM in estimating the energy output. Also, by better examining the results, it is clear that the evaluation criteria of the training period always have less error than the test period, which indicates the absence of errors during network training. Actual and predicted data values of garden thyme and peppermint plants' energy output against the number of data

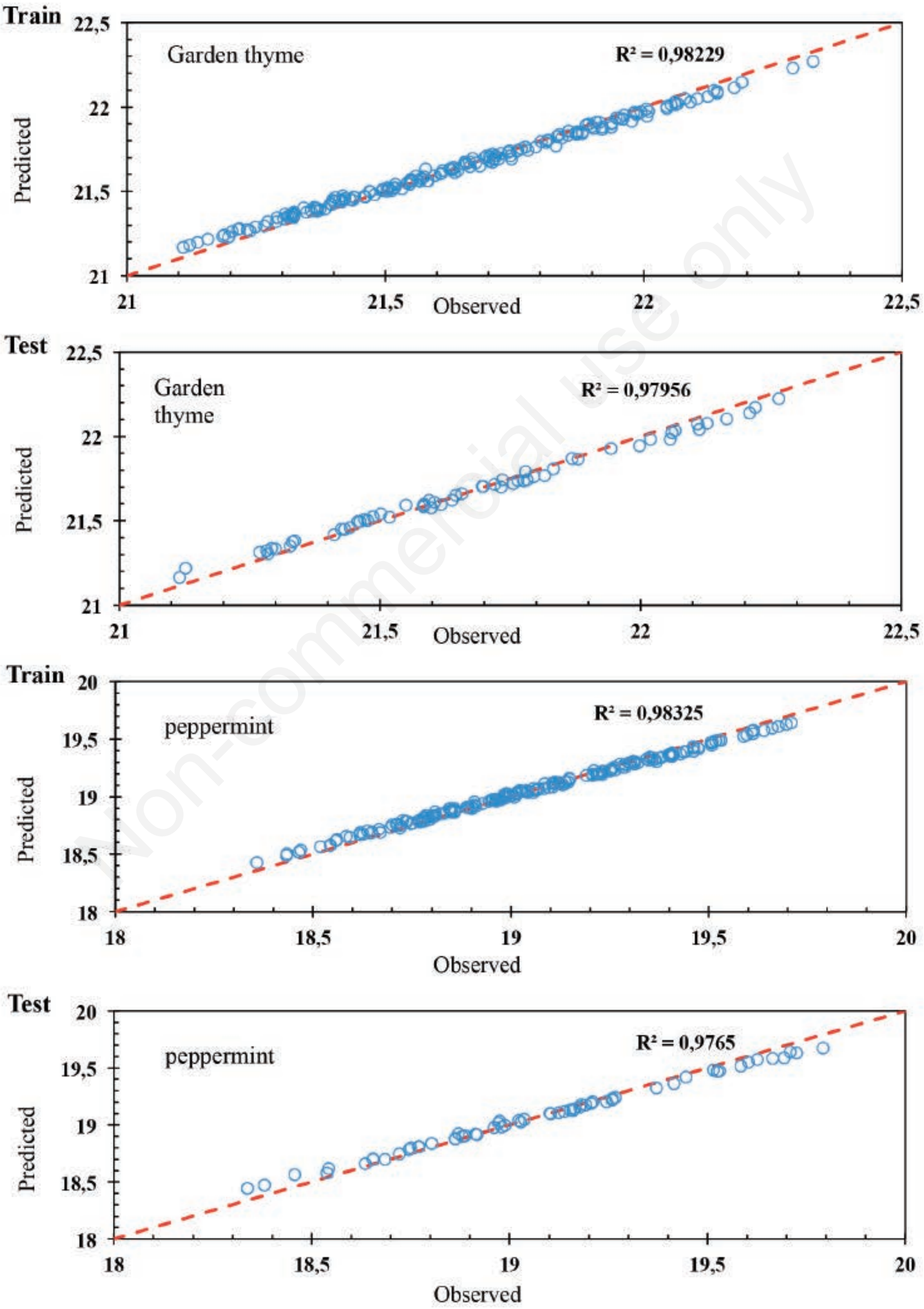


Figure 6. Scatter curve of actual data and predicted energy output for garden thyme and peppermint.

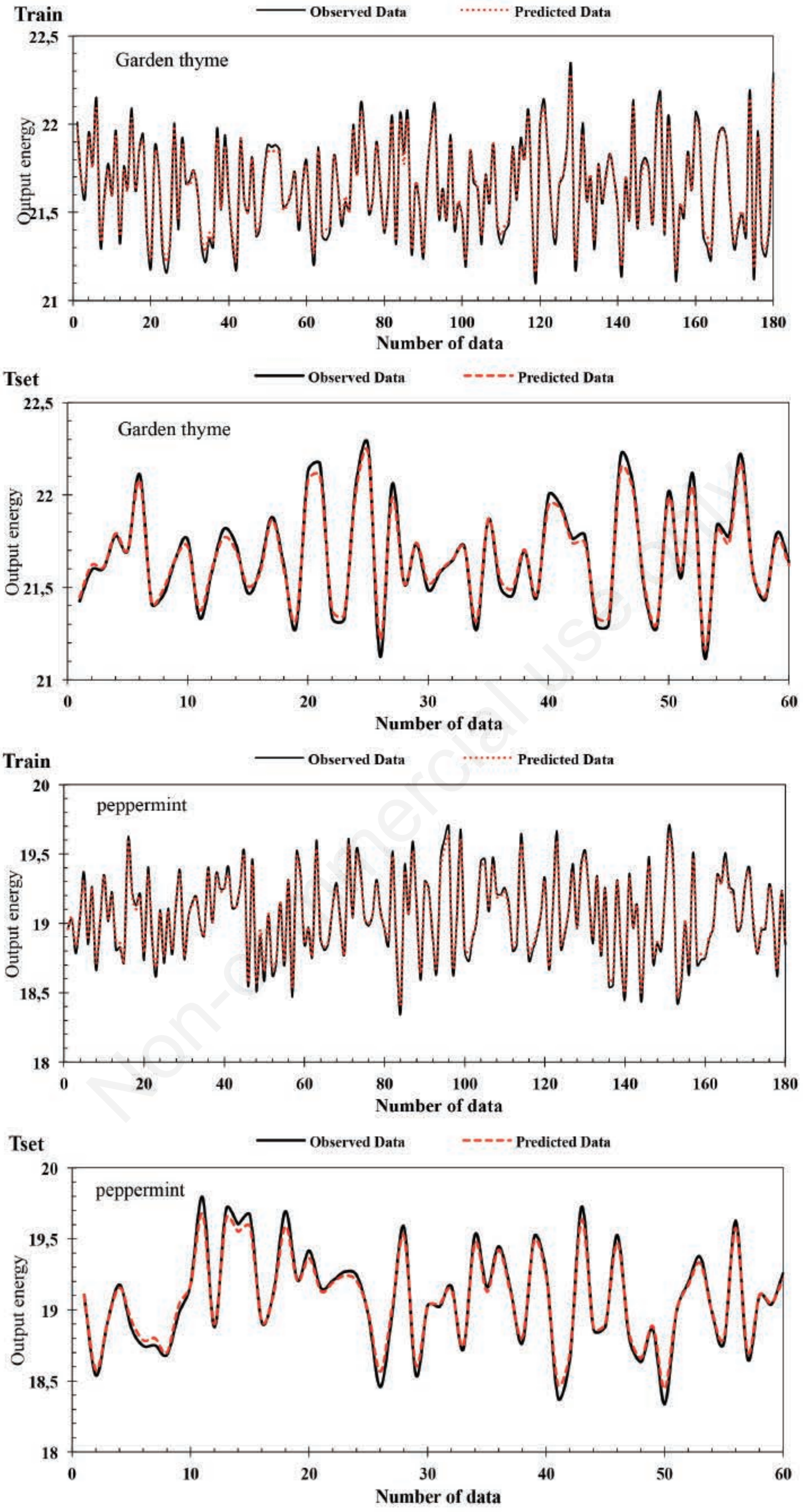


Figure 7. Graph of actual and predicted energy output data against number of data for garden thyme and peppermint.

for the test and training phases are presented in Figure 7. It was observed that at the maximum points, the actual output energy always had higher values and the SVM estimated the output energy with a little error and lower values than the reality. In the minimum output energy points, it can be seen that the actual values for garden thyme and peppermint plants are always lower than the output results of the SVM . In other words, it can be said that the accuracy of the algorithm is high in the range of average output energy and the algorithm has a very small error in the minimum and maximum points. Of course, during the estimation process, it is observed that the output data of SVM is always close to the real values and has a good match.

Conclusions

Although in appearance, in systems where more energy is spent in crop production, each crop unit is produced at a higher cost. However, the high economic efficiency of plants compared with other plants in the cultivation of patterns in the region and farm development of garden thyme and peppermint has economic advantages because of the high value of thyme and peppermint. Moreover, garden thyme and peppermint are very expensive, and it creates more employment in rural areas, and many villagers get jobs by working on farms. There are fewer fossil fuels in the cultivation of garden thyme and peppermint, and plants interact with their environment. Although the energy situation is uncertain and the price of energy generally changes globally, labor in villagers depends heavily on agriculture in the country, especially in Alborz and Tehran province, but there is high unemployment. Development of cultivation area of plants that reduce reliance on high-input production systems and foreign input can create more employment. However, garden thyme and peppermint are planted with organic agriculture techniques in this region, and this agricultural system can be seen as a way to sustain the cultivated ecosystems and preserve biodiversity. Manure and labor are the right way to increase sustainable production systems (sustainable farming system), especially the cultivation of plants increases agricultural income and economic growth. It is one of the basic principles of sustainability in agricultural production systems. Considering that in economic discussions, in addition to labor and capital inputs, energy is also mentioned as one of the important production inputs. The importance of energy in the production process of various products, on the one hand, and its scarcity, on the other hand, require more and more attention from economic operators for the efficient use of this factor. Therefore, by predicting the amount of energy output as accurately as possible, it can play a decisive role in the economic life of countries. Therefore, in this research, the SVM model was used to estimate the energy output of medicinal plants of garden thyme and peppermint. For this purpose, out of 240 real data series, 180 data were used for network training, and 60 data were considered for network testing. The results showed that the SVM method has a high ability to estimate the energy output of garden thyme and peppermint plants in such a way that the coefficient of determination between the actual values and the predicted values for the garden thyme plant for the test period equals R^2=0.9796 and for the peppermint plant It is equal to R^2=0.9765. In general, the results of this study showed that the SVM can be used as a new method for estimating the energy output of agricultural products.

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