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YIELD, ENERGY AND ECONOMIC ANALYSIS OF GREENHOUSE CUCUMBER (CUCUMIS SATIVUS L.) PRODUCTION UNDER DIFFERENT FARMING TREATMENTS

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ABSTRACT

Agrochemical based agriculture production is neither sustainable nor eco-friendly. A cost effective and sustainable organic farming is the need of time for better yield and quality. The efficient use of energy inputs improves productivity, profitability and economy. In this regard, we carried out this research for greenhouse hybrid cucumber (Kalam F_1) production at Institute of Hydroponic Agriculture, Rawalpindi for the year 2017 to 2019 cropping season. The main objective was to evaluate the yield, energy and economic feasibility of greenhouse cucumber production under different farming treatments such as inorganic, organic and integrated fertilization application. The analysis was carried out based on energy use efficiency, energy productivity, benefits to cost ratio and amount of renewable and nonrenewable energies. The obtained results depicted that the total energy inputs for inorganic, organic and integrated greenhouse productions were 45856.3, 42945.3 and 54070.0 MJ ha^{-1}, respectively. Energy use efficiency was 4.19, 4.84 and 4.87 while the energy productivity was 1.25 kg MJ^{-1}, 1.26 kg MJ^{-1} and 1.40 kg MJ^{-1} under inorganic, organic and integrated fertilizer treatments, respectively. The average percentages of direct, indirect, renewable and non-renewable energies were 11%, 32.9%, 11.7% and 32.2% of the total energy, respectively. The net return of integrated farming treatment was highest (43135.60 \$ ha^{-1}) than organic (23555.33 \$ ha^{-1}) and inorganic (25127.93 \$ ha^{-1}) farming treatments. Similarly, the benefit to cost ratio were 7.75, 6.03 and 6.57, respectively from integrated to inorganic farming treatments. According to results, greenhouse cucumber production under integrated treatment showed high energy use efficiency, energy productivity, net return and benefit to cost ratio in comparison with organic and inorganic treatments which proved to be profitable practice for greenhouse cucumber production than organic and inorganic farming treatments.

Keywords: Greenhouse production, Cucumber, Organic farming, Energy analysis, Profitability.

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INTRODUCTION

The imminent possibility of decreasing crop productivity arises due to continuous application of inorganic (synthetic) crop inputs, extreme use of irrigation and improper land management requires the adaptation and promotion of sustainable agriculture farming system. Organic agriculture utilizes all organic inputs during entire crop period, same as sustainable agriculture, as it has negligible negative affect on ecological health therefore, crucial to attain high agricultural production. Application of organic inputs promote soil fertility, biodiversity, public adaptation and entire shift toward organic agriculture belongs to sustainable agriculture (Kilcher, 2006; Noor *et al*., 2020a). A legitimate organic production system improves crop yield, alleviate crop returns and therefore, reduces food insecurity, mainly for small landholders.

Some studies considered economics sustainability (profit margin) as necessary for agricultural sustainability (Aslam *et al*., 2017). Additionally, the sustainable agriculture relates to three main characteristics such as maintaining better environmental quality, stability in productivity and social acceptability. Compared with conventional agriculture, the organic production system performs better in term of economics (Rigby and Caceres, 2001). Aslam and Hong, (2018a) stated that organic crop production system may not be considered the sustainable agriculture in all over the situations like in case of nitrate losses, there is a need to supply sufficient nutrient quantity through application of organic inputs. Aslam and Hong, (2018b) considered minimum application of inorganic fertilizer as a compulsory option for better crop productivity and sustainable agriculture. De Jager *et al*., (2001) interested in enhancing production, found it necessary to use inorganic input to some extent integrated with organic inputs in order to provide required nutrients for better soil health and crop yield.

The most intensive sector of world agriculture production is greenhouse agriculture system. It is intensive in sense of crop yield, annual production, energy consumption, investments and cost (Omid *et al*., 2011). Greenhouse farming enables the evaluations of small areas by providing high yield per unit area, besides it needs a regular labor use for agricultural activities. Similarly, agriculture under greenhouse increase water productivity, soil resource efficiency, and necessitate the profitable use of the water resources under restricted water availability due to global warming and increased water demand.

Greenhouse farming can be executed as single and double cropping. Single cropping is generally done in glass covered greenhouse and mono crop is obtained in a year. Double cropping is done in plastic cover greenhouse, the first crop is obtained in autumn, and the second crop is obtained in spring. A major part of the crops in the greenhouse are consumed in domestic markets and approximately 12% of these crops are exported.

In Pakistan, tomato, cucumber, pepper and other main consumable vegetables production are mainly carried under greenhouse with 79.9% of the total area under vegetable production. Tomato has the biggest share of production with 48% among the four crops while cucumber, pepper and others with 23.5%, 16.6% and 9.3% of total area under vegetable, respectively. Other vegetable kinds such as melon, bean and squash are grown in the greenhouses with the share of 2.6%.

Energy use in a high yield agro-ecosystem such as greenhouse has become more intensive energy option due to the intensive use of energy inputs. The efficient use of energy resources increases crop production prevents frequent damage to natural resources and promote agricultural sustainability as an economical agricultural production system (Dalgaard *et al*., 2001). The greenhouse production is one of the most intensive crop production system and an energy-consuming branch in agriculture. In this system, the energy budget is important that is the numerical comparison of the relationship between inputs and outputs of a crop production system in terms of energy units (Canakci and Akinci, 2006).

Agricultural production and energy consumption are closely linked to each other. The efficient and effective use of energy is the key to enhanced sustainability of the agriculture production (Mohammadi and Omid, 2010). The units of energy use for agricultural production has been increased due to the use of pesticides, fertilizers, machinery, fuel, and electricity. The intensive energy use has produced environmental and human health problems; consequently, the efficient use of agricultural crop energy inputs has become an important factor for sustainable agriculture production (Yilmaz *et al*., 2005).

Energy productivity is an important index to determine the efficient use of energy inputs although higher energy productivity does not mean more economic possibility. However, energy input-output analysis describes the method to increase energy productivity by reducing energy inputs (Çebi *et al*., 2019). Increasing the energy efficiency of greenhouse production system is one of the most required energy studies in agriculture and the success in increasing energy efficiency in greenhouse farming determines the efficient use of energy resources. For this purpose, the input-output analysis in greenhouse is used to evaluate the environmental impacts and energy use efficiency of greenhouse organic and inorganic farming systems.

Several research studies were carried out on energy use efficiency and economic analysis of greenhouse cropping system to improve input-output energy analysis and evaluate the correlation between them, to name a few; Singh *et al*., 2003; Yuan and Peng, 2017; Noor *et al*., (2020b) Naresh *et al*., 2018; Yildizhan and Taki, 2018; Ilahi *et al*., 2019. Ekinci *et al*., (2020) investigated energy use for fruit production to improve energy efficiency. Aydin *et al*., (2019) investigated input-output energy relation to optimize energy sources for production of apricot. Mohammadi and Omid (2010) explored the energy budget in greenhouse cucumber cultivation in Iran. Ali *et al*., (2019) first time explored the energy ratios, energy forms, and GHG emission in the cultivation of cucumber under tunnel farming in Pakistan. Aslam *et al*., (2020) did the economic analysis of grafted cucumber production system in comparison with the real rooted hybrid-cucumber production system. However, in vegetable production system, researches conducted on energy use pattern are insufficient and demanded a detail exploration of utilization energy inputs and sources availability in greenhouse vegetable production. Thus, this research was carried out with specific objectives to (a) evaluate the energy input-output relationship for greenhouse cucumber production under organic, inorganic and integrated farming treatments (b) evaluate energy efficiency, energy productivity and their relationships for different farming treatments (c) evaluate the economics of different farming treatments in order to check suitability and acceptability.

MATERIALS AND METHODS

This experimental study was conducted for three consecutive seasons of 2017 to 2019 under controlled conditions (Temperature 28 ℃ and 90% humidity) with different fertilizer options in glass covered greenhouse at Floriculture Research Station, Institute of Hydroponic Agriculture located near Rawat, a 30 km from Rawalpindi on the way to Grand Trunk (GT) Road. The hybrid cucumber (Kalam F_1) was used as a material of the trails. The mentioned cultivars were mostly preferred because of better plant physiological growth, high fruit yield, and quality and highly resistive against soil borne diseases (Noor *et al*., 2019b; Aslam *et al*., 2020).

Scion and rootstock nursery were prepared in the first week of August during all three seasons in with peat moss and vermiculate ratio 1:1 (v/v) as growing media to maintain better air–water composition. After 15 days, the grafting was performed depending upon the diameter of scion and rootstock and the grafts were shifted into disposable plastic pots filled with same growing media. Before the grafting process, plant material and tools were interacted with laminar flow of UV light to kill microbes. After 30–35 days, the grafted plants under uniform growing (temperature and humidity) conditions were transplanted into greenhouse having 20 m x 50 m (1000 m^2) dimensions. The land was prepared conventionally for all treatments using M.B plough, Disc harrow, cultivator and soil leveler (Noor *et al*., 2019a). The soil characteristics were pH 7.3, electrical conductivity (EC) 0.14 mS cm^{-1}, NO_3 15 mg dm^3, P 4 mg·dm^3, K 31 mg dm^3, Ca 28 mg dm^3, Mg 17 mg dm^3, and total nitrogen 0.25%. A recommended dose (25 tons) of well rotten farmyards manure was applied in relevant treatment (Organic, T_2) combinations plots at the time of sowing while, the complete dose (120 kg ha^{-1} each) phosphorus and potassium in the form of di-ammonium phosphate and murate were applied in T_1 inorganic treatment. The urea fertilizer (nitrogen) was fed in two equal doses at planting and flowering stages. The fertilizer as per treatments was thoroughly mixed in the soil with the help of weeding hoe. The trail was carried out according to completely randomized design (CRD) with three replications under each fertilizer treatment as shown in Table 1. Table 1 also presented the quantity of fertilizer applied under each treatment. The main objective of this study is the evaluation of energy input-output analysis of selected treatments, and to achieve the specific objective the major focus is on the energy use and economic analysis as described below.

Table 1. Fertilizer treatments and doses.

Fertilizer Treatments	Description
Inorganic (T_1)	NPK (Recommended dose, 150,120,120 kg ha^{-1})
Organic (T_2)	FYM (Recommended dose, 25 tones)
Integrated (T_3)	NPK (50%) + FYM (Recommended dose, 25 tones)

Energy input-output analysis: The cucumber production systems involved several operations during entire crop period, and their energy requirements affect the total energy budget. For the calculation of energy equivalents for per hectare, the data comprised of the quantities of various energy inputs used per hectare was calculated for greenhouse cucumber production under three different farming treatments. Like, tractor use in farming operations, diesel fuel, chemicals, labor power, fertilizers, manure, irrigation water, electricity and seed and the production yields as outputs. All inputs were recorded per hectare basis. The amounts of inputs and outputs were calculated per hectare and multiplied by the energy equivalent coefficients. The calculations of experimental data were performed according to the averages of three years data. Energy equivalents for the inputs and outputs for greenhouse cucumber production were obtained from the previous studies as presented in Table 2. The energy equivalent coefficient showed the amount of energy (measured in MJ) received from the use of 1 unit of input like human labor (1.96 MJ h^{-1}), agricultural machinery (62.7 MJ h^{-1}), nitrogen (60.6 MJ kg^{-1}), phosphorus (11.15 MJ kg^{-1}), potassium (6.7 MJ kg^{-1}), farmyard manure (0.3 MJ kg^{-1}), cucumber nursery (0.18 MJ kg^{-1}), irrigation water (1.02 MJ cubic $meter^{-1}$), and diesel fuel (50.23 MJ $litre^{-1}$) etc. The source of mechanical energy included direct use of tractors and consumed diesel oil. The mechanical energy was computed on the basis of total fuel consumption (L ha^{-1}). Therefore, the energy consumed was calculated using conversion factors and was expresses in MJ ha^{-1}. Total input energy consumption was estimated by the addition of energy values from each input. Total output energy was calculated by multiplying total cucumber production with the energy equivalent of cucumber (0.8 MJ kg^{-1}).

The expression used to determine energy use efficiency (energy ratio), energy productivity, specific energy and net energy are given as (Ozkan *et al*., 2011).

$$E \quad u \quad e = \frac{E \quad O \quad (M\ ha^{-1})}{E \quad I \quad (M\ ha^{-1})} \qquad (1)$$

$$E \quad p = \frac{Y \quad (k\ ha^{-1})}{E \quad I \quad (M\ ha^{-1})} \qquad (2)$$

$$S \quad e = \frac{E \quad I \quad (M\ ha^{-1})}{Y \quad (k\ ha^{-1})} \qquad (3)$$

$$N \quad e = E \quad O \quad (M\ ha^{-1}) - E \quad I \quad (M\ ha^{-1}) \qquad (4)$$

Table 2. List of energy equivalents of inputs and outputs in cucumber production.

Energy sources	Energy Equivalent (MJ unit^{-1})	Literature cited
Inputs		
Human labor (h)	1.96	(Ozkan *et al*., 2011).
Fertilizer and pesticides (kg)		
Nitrogen (N)	60.6	Mengistu *et al*., 2018
Phosphorous (P_2O_5)	11.15	Mengistu *et al*., 2018
Potassium (K_2O)	6.7	Mengistu *et al*., 2018
Sulphur (S)	1.12	Mohammadi *et al*., 2008
Zinc (Zn)	8.4	Mohammadi *et al*., 2008
Insecticides	101.2	Pellegrini and Fernández 2018; Houshyar *et al*., 2015
Fungicides	181.9	Pellegrini and Fernández 2018
Herbicides	238.3	Pellegrini and Fernández 2018
Farmyard manure (kg)	0.3	Mohammadi *et al*., 2008
Seed (kg)	1.0	Pellegrini and Fernández 2018
Diesel fuel (l)	50.23	Nabavi *et al*., 2016
Electricity (kWh)	3.6	Saad *et al*., 2016; Mohammadi *et al*., 2008
Tractor (kg)	93.61	Khan *et al*., 2018
Electric motor (kg)	64.8	Prajapat *et al*., 2018; Härtl *et al*., 2019
Agricultural machinery (kg)	62.7	Prajapat *et al*., 2018; Härtl *et al*., 2019
Irrigation water (m^3)	1.02	Ozkan *et al*., 2011
Plastic general (kg)	90	Ozkan *et al*., 2011
Wood (kg)	18.9	Ekinci *et al*., 2020
Cucumber nursery	0.18	Calculated
Outputs		
Cucumber production (kg)	0.8	Elisabeth *et al*., 2019; Pellegrini and Fernández 2018
Straw yield (kg)	7.5	Pellegrini and Fernández 2018

Total energy inputs in cucumber production was also categorized as direct and indirect or alternatively as renewable and non-renewable energies (Bolandnazar *et al*., 2019). The direct energy comes from human labor, diesel fuel, and water for irrigation and electricity. The indirect energy includes fertilizer, pesticides, seed, machinery and farmyard manure. The non-renewable energy comes from diesel fuel, machinery, pesticides, fertilizers, and electricity. The renewable energy includes seeds, water for irrigation, manure and human labor.

The construction cost and embodied energy employed in the construction of the greenhouse was also calculated depending upon region. The effectively used area of the greenhouse was 20 m x 50 m (1000 m^2). The height of greenhouse was 2.0 m but, the center was 5.5 m high and the volume was 3750 m^3. The surface of the greenhouse is covered with a 3 mm thick glass and the structural material was iron. The foundation was built with 0.25 m thick concrete wall as boundary of floor area. Table 3 showed the list of materials used in the construction of the greenhouse (Tavares *et al*., 2019; Teh *et al*., 2019). In this research, the average market prices were used for the estimation of the construction cost for the greenhouse.

Table 3. Energy embodied, and cost used for the construction of greenhouse (20×50 m^2).

Item	Energy embodied			Total Cost	
	Unit	(MJ unit^{-1})	**Total energy** (MJ)	**Rate** ($)	**Cost** ($)
Metal (Iron), kg	9025	27.73	250263.25	0.45	4061.25
Glass, kg (m^2)	10900 (1445)	12.7	138430	6.7	9681.5
Cement, kg (bag)	1000 (20)	7.79	7790	2.93	58.6
Sand, kg	41500	0.08	3320	2.5	103750
Screw, kg	80	31.06	2484.8	1.72	137.6
Putty, kg	1300	18.01	23413	0.83	1079
Paint, kg	63	90.4	5695.2	1.72	108.36
Metal wire rods, kg	92	12.5	1150	1.38	126.96
Labor cost	-	-	-	1586	1586
Total			**432546.25**		**120589**

The greenhouse was considered as 25 years life according to regional and material properties, the greenhouse embodied energy is 17,264.1 MJ per 1000 m^2 cucumber production area for one year. The energy primarily used in different agricultural operations is listed in Table 4. Agricultural machinery and tractor use energy was estimated using following expression (Li *et al.*, 2019).

$$M = \frac{G \times M \times 1}{T \times W} \qquad (5)$$

Where M is machine energy (MJ ha^{-1}), G is the wight of machine (kg), M is the production energy (MJ kg^{-1}), T is the total life (h) and W is the effective field capacity (ha h^{-1}).

Diesel energy was measured by quantity of fuel consumed during crop production (Li *et al.*, 2019).

$$FC = P_m \times R \times SFC \qquad (6)$$

Where FC is the fuel consumprion (l h^{-1}), P_m is the tractor horsepower (kW), R is the loading ratio and SFC is specific fuel consumption taken as 0.3 l kWh^{-1}.

Computerized data acuistion system consisted of a dynamometer (50 kN), torque meter (2000 Nm), data logger and a laptop was used to measure machines loading ratio. Electricity consumption for irrigation and spraying activities was counted by electric meter.

Table 4. Energy sources used in greenhouse cucumber production under different farming treatments.

	Treatments		
Operations (unit ha^{-1})	**Inorganic (T_1)**	**Organic (T_2)**	**Integrated (T_3)**
Solarization			
Man (h)	42.6	42.6	42.6
Irrigation system (h)	6.0	6.0	6.0
Irrigation water (m^3)	600	600	600
Electricity (kWh)	7.5	7.5	7.5
Nylon (kg)	10.0	10.0	10.0
FYM application			
Man (h)	0.0	27.1	28.3
Tractor (h)	0.0	4.1	4.5
Diesel (l)	0.0	9.3	10.2
FYM (t)	0.0	25.0	25.0
Land preparation			
Man (h)	49.0	49.0	49.0
Tractor (h)	2.7	2.7	2.7
Diesel (l)	6.5	6.5	6.5
Nursery transplanting			
Man (h)	25.5	24.5	25.2
Cucumber nursery	50.0	50.0	50.0
Plant husbandry			
Man (h)	275.0	271.0	275.0
Strings (kg)	18.6	18.6	18.6
Plant protection			
Man (h)	38.3	0.0	37.6
Spray equipment	38.3	0.0	37.6
Electricity (kWh)	36.1	0.0	35.9
Insecticides	15.5	0.0	14.4
Fungicides	6.5	0.0	6.3
Fertilizer and irrigation			
Man (h)	16.0	15.0	16.0
Irrigation system (h)	92.6	89.5	92.0
Irrigation water (m^3)	3000.0	2700.0	2900.0
Electricity (kWh)	115.7	113.0	115.0
N, P, K (kg)	105.5,32.5,66.5	0,0,0	50,17,35
Heating			
Man (h)	78.8	78.8	78.8
Heating equipment (h)	78.8	78.8	78.8
Wood (kg)	748.0	748.0	748.0
Ventilation			

Man (h)	16.5	16.5	16.5
Crop harvesting			
Man (h)	348.0	348.0	348.0
Transportation			
Man (h)	50.3	50.3	52.3
Tractor (h)	50.3	50.3	52.3
Diesel (l)	62.1	62.1	63.1
Cleaning up			
Man (h)	20.3	20.3	20.3
Output			
Cucumber yield (kg)	57333	54285	75678
Straw yield (kg)	19500	21900	27070

The tractor power or electric power was used to operate agricultural machinery for cucumber production, while transplanting, plant husbander, harvesting and cleaning up operation were carried out manually. Between July and August, the soil sterilization was performed by solarization process through covering soil surface with plastic sheet and setting up irrigation system. An electrical motor operated two-wheel sprayer with 200 litre spray tank capacity was used for spraying. Drip irrigation method was used in greenhouse including fertigation system. The locally iron sheet wood furnace was used for heating greenhouse, essentially during winter time when temperature drops below required temperature. Natural ventilation was done using manual windows. The cucmber fruite harvesting was performed manually.

Economic analysis: The economic analysis of cucumber production was done. The economic inputs of hybrid cucumber production mainly based on total fixed and variable costs (Benli, 2019; Mohamed *et al.*, 2017). The variable costs included the costs of chemicals, fuel, human labor, seed, fertilizers, irrigation water, electricity, repair and maintenance and revolving interest. The fixed costs included general administration expenses, interest on land value, irrigation machine tools interest, irrigation machine tools depreciation value, the amortization of facility costs, the facility capital interest. Following formulae were used in the calculation of gross, absolute and relative profit indicators (Baran *et al.*, 2017).

$$G \quad r = Y \quad (k \; ha^{-1}) \times Y \quad p \quad (\$/k \;) \tag{7}$$

$$G \quad p = G \quad r - v \quad c \quad (\$/ha) \tag{8}$$

$$N \quad p = G \quad r - p \quad c \quad (\$/ha) \tag{9}$$

$$R \quad p = \frac{G \quad r}{P \quad c} \tag{10}$$

RESULTS AND DISCUSSION

Analysis of energy use in greenhouse cucumber production: The results obtained for the operational energy requirements (inputs) for cucumber production under inorganic, organic and integrated treatment systems were calculated as 45856.3, 42945.3 and 54070.0 MJ ha^{-1}, respectively (Table 5). The share of heating energy is highest in all treatments followed by irrigation and fertilization (20.3% in T_1 and 17% in T_3) and FYM application (19.6% in T_2). The heating energy 19232.4 MJ ha^{-1} was observed highest among all other input energy sources due to climatic and geographical conditions. According to weather reports, generally the air temperature start dropping from 28℃ in first week of October and remain below in whole winter season. Therefore, it is obvious, a greenhouse needs proper heating system. The greenhouse heating was done using high energy wood material. In heated greenhouse, the energy input associated with heating fuel is significantly high. This experimental study was carried out in heated greenhouse so that high heating fuel consumed in the greenhouse. In order to improve the energy use, it is suggested that production should be done under unheated greenhouse or, if not possible, the heating system efficiency should be raised or substituted with cheap energy sources such as renewable (natural gas and/or solar) energy (Omid *et al.*, 2011).

The maximum use of irrigation and fertilization energy was measured as 9313.9 MJ ha^{-1} in inorganic cucumber production (treatment T_1) followed by integrated production (9171.8 MJ ha^{-1} in treatment T_3) while the lowest energy (3366.0 MJ ha^{-1}) was measured in organic production in treatment T_2 because no chemical fertilizers were applied. Some operations did not use energy consumption and their values were set to zero such as spraying energy in organic cucumber treatment T_2 and farmyard manure (FYM) application energy in inorganic treatment T_1. The energy share in FYM application 8404.1 MJ ha^{-1} was kept similar both in organic and integrated production systems.

The total output energy is the sum of cucumber yield energy and straw yield energy. It was calculated with the measured quantities of cucumber yield and straw yield in Table 4. Total production of cucumber was 57333 kg ha^{-1}, 54285 kg ha^{-1}, and 75678 kg ha^{-1} for T_1, T_2 and T_3 treatments, respectively (Table 4). The treatment T_3 (integrated production system) showed highest (263567.4 MJ ha^{-1}) total energy output followed by treatment T_2 organic cucumber production (207678.0 MJ ha^{-1}) and the lowest (192116.4 MJ ha^{-1}) was observed in inorganic production system, treatment T_1.

Table 5. Energy use and output in cucumber production under greenhouse.

Operation	Treatments					
	Inorganic (T_1)		Organic (T_2)		Integrated (T_3)	
	Energy (MJ ha^{-1})	(%)	Energy (MJ ha^{-1})	(%)	Energy (MJ ha^{-1})	(%)
Solarization	1998.7	4.4	1998.7	4.7	1998.7	3.7
FYM application	0.0	-	8404.1	19.6	8404.1	15.5
Land preparation	675.3	1.5	675.3	1.6	675.3	1.2
Transplanting	59.0	0.1	57.0	0.1	58.4	0.1
Plant husbandry	539.0	1.2	531.2	1.2	539.0	1.0
Spraying	5357.4	11.7	0.0	-	5163.7	9.6
Irrigation and fertilization	9313.9	20.3	3366.0	7.8	9171.8	17.0
Heating	19232.4	41.9	19232.4	44.8	19232.4	35.7
Ventilation	32.3	0.1	32.3	0.1	32.3	0.1
Harvesting	682.1	1.5	682.1	1.6	682.1	1.3
Transportation	7926.5	17.3	7926.5	18.5	8070.5	14.9
Cleaning up	41.7	0.1	39.8	0.1	41.7	0.1
Total energy input	**45856.3**	**100.0**	**42945.3**	**100.0**	**54070.0**	**100.0**
Cucumber yield	45866.4	-	43428.0	-	60542.4	-
Straw yield	146250.0	-	164250.0	-	203025.0	-
Total energy outputs	**192116.4**	**-**	**207678.0**	**-**	**263567.4**	**-**

Equations 1 to 4 were used to calculate the energy use efficiency, energy productivity, specific energy and net energy of cucumber productions for all treatments. Energy use efficiency were calculated as 4.19, 4.84 and 4.87 in inorganic, organic and integrated production systems, respectively (Fig.1). The organic and inorganic treatments showed significantly similar energy use efficiency. This depicted the efficient use of energy input sources in greenhouse cucumber production. The score of energy efficiency is better as compared to previous research studies such as 0.69 (Omid *et al.*, 2011), and 0.64 (Mohammadi and Omid, 2010). Others calculated energy use efficiency for greenhouse cucumber productions as 0.27 (Sami and Rehani, 2015) in Iran, 0.33 (Yousefi, *et al.*, 2012) in Iran, 0.31 (Canakci and Akinci, 2006) in Turkey, 0.38 (Kuswardhani *et al.*, 2013) in Indonesia, 0.56 (Taki *et al.*, 2012) in Iran, and 0.76 Ozkan *et al.*, 2011) in Turkey. Energy use efficiency is the ratio between total energy output to total energy input and it shows that the output energy was 4.19 MJ, 4.84 MJ, and 4.87 MJ for the use of 1 MJ energy as an input for treatments T_1, T_2 and T_3, respectively. In this study the residue of crops collected as straw yield is also incorporated to calculate the total output energy to make the system more efficient and stable.

The energy productivity of cucumber crops under treatment T_1, T_2 and T_3 were calculated as 1.25, 126 and 1.40 kg MJ^{-1} of three cucumber production systems, respectively. This indicated that 1.25, 1.26- and 1.40-unit outputs were received per unit of input energy consumed. Energy productivity is more as compared to 0.80 Kg MJ^{-1} (Mohammadi and Omid, 2010). The specific energy is an index that indicates how much energy is utilized to produce a single unit of product. The specific energy of cucumber crop was calculated as 0.80 MJ kg^{-1}, 0.79 MJ kg^{-1} and 0.71 MJ kg^{-1} for inorganic, organic and integrated greenhouse production systems. This showed that one kg of cucumber production required such amount of energy, respectively under T_1, T_2 and T_3 treatments. The specific energy was less than 1 for all treatments which is less as compared with 1.72 MJ kg^{-1} (Abdi *et al.*, 2012). Net energy means the difference between energy used and energy output. The calculated net energy of greenhouse cucumber production was maximum (209497.44 MJ ha^{-1}) under integrated fertilizer option (T_3) followed by T_2 (164732.72 MJ ha^{-1}) organic fertilizer system while, the lowest positive net energy (146260.08 MJ ha^{-1}) was calculated for inorganic fertilizer treatment. The net energy values were positive for all treatments that showed no energy lost during cucumber production in greenhouse systems. The energy budgeting (energy use efficiency > 1; energy productivity > 1; specific energy < 1; and net energy > 0) implies that the cucumber cultivation under greenhouse system is feasible but higher cucumber yield under integrated fertilizer treatment T_3 make the greenhouse cucumber production more feasible and adoptive.

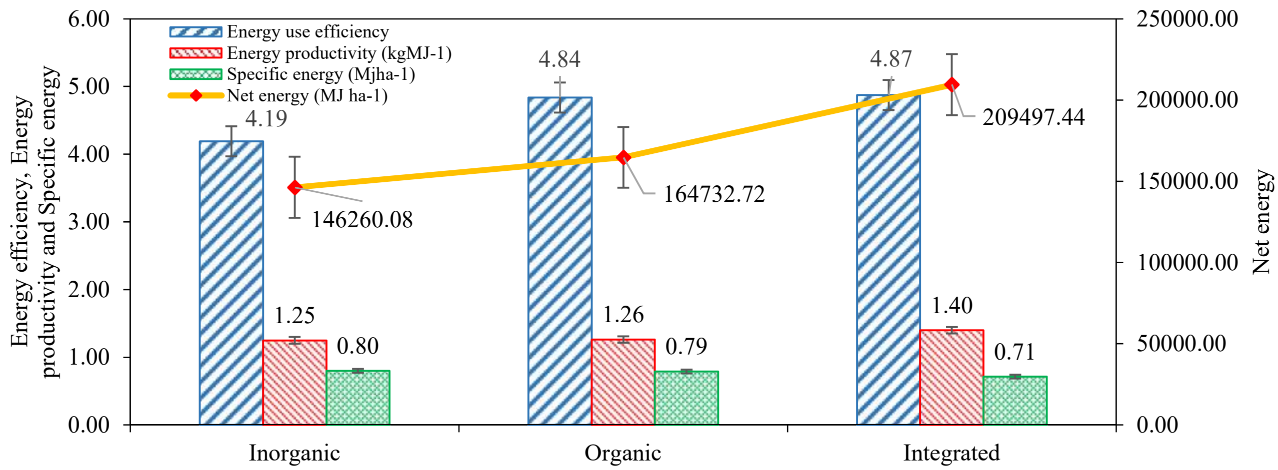

Figure 1. Energy budgeting parameters for cucumber production under different fertilizer treatments.

Energy utilization in different sources of cucumber production*:* The total energy utilized from multiple energy sources were 93631.8 MJ ha^{-1}, 84935.6 MJ ha^{-1} and 89226.9 MJ ha^{-1} to produce cucumber under integrated, organic and inorganic production systems, respectively (Table 6). Among the different utilized energy sources, the greenhouse structure, agricultural machinery, tractor and wood energies were calculated highest with a mean value of 36169.4, 17892.6 and 14137.2 MJ ha^{-1}, respectively and accounts approximately 75% of the total energy utilized from different energy sources. These high-energy input sources can affect the ratio of other input energy sources. In this research study, the greenhouse was covered with glass material, which also contributed as high-energy value. This glass material significantly increased the total structural energy of greenhouses. The results suggested the needs to consider the use of glass greenhouse farming for better energy efficiency.

The fertilizer energy in organic production was zero while, in integrated cucumber production system the fertilizer energy was half of the energy used under inorganic cucumber production system. On the other hand, both organic and integrated production systems received equal FYM energy but not in inorganic cucumber farming. The spray material energy was in range 2603.3 to 2751.0 $MJha^{-1}$ in all treatments and were almost similar because of using same amount of chemical spray.

The results are not associated with high cucumber productions and a greater number of transportation cycles. In all production systems, the machinery energy ranges from 16273.17 to 18918.9 MJ ha^{-1}. Each number of spraying and transportation increased machinery energy by 5.6%. The electric energy utilization was found fractionally varied because of using same operations. The highest values 3.6% was calculated under inorganic cucumber production due to high-powered electric pump used for spraying and irrigation operations. Plastic and plant energy were same in three production systems while the irrigation energy was less in organic production than other two production systems. Under such production systems, the efficient use of input energy sources could help to attain high production and productivity and resulted in an economical practice and higher profitable greenhouse production (Mohammadi and Omid, 2010).

The other variables*:* The cucumber yields (57,333 and 19,500 and 54,285 kg ha^{-1}) and straw yields (21,900 and 75,678 and 27,070 kg ha^{-1}) of cucumber was calculated from inorganic, organic and integrated greenhouse production systems, respectively. The energy ratio was calculated maximum in integrated cucumber production followed by organic production and inorganic production system. The specific energy requirement was highest in inorganic production 0.8 MJ kg^{-1} followed by organic production (0.79 MJ kg^{-1}) and integrated cucumber production (0.71 MJ kg^{-1}). The energy productivity in greenhouse cucumber production ranges from 1.25 to 1.40 MJ kg^{-1}. The calculated output energy sources were different to other studies. Many other earlier researches showed the energy ratios of greenhouse vegetable production were lower ranges from 0.19 to 0.32 that are due to high greenhouse structural, agricultural machinery and heating energies.

Energy inputs as direct, indirect, renewable and non-renewable forms are given in Table 7. These are different forms of energy in cucumber production under three treatments. The results showed that shares of non-renewable energy are higher than all other forms in all treatments followed by indirect energy and direct energy. Consistently the share of non-renewable energy was maximum (89.07%) in greenhouse cucumber in Iran (Mohammadi and Omid, 2010). The share of direct and indirect energy in the integrated cucumber production was calculated as 11.7 and 34.6% of total energy input, respectively while it was 12.6 and 28.1% in organic treatment of cucumber (Table 7). The percentages of renewable energy (6.2, 15.0 and 13.9) and non-renewable energy (52.2, 41.2 and 46.6) for three greenhouse production systems respectively indicated that inorganic treatment use major share of non-renewable energy. The share of renewable energy is high in organic treatment than integrated and inorganic treatments because of FYM application energy. It is also required to increase the share of renewable energy in green production for the protection of environment. Renewable energy sources are clean and green energy sources and should be adopted and encouraged for greenhouse cucumber production for better environmental impact and energy conservation. On the other hand, non-renewable sources are limited and are depleting with time. The results showed that the greenhouse production mainly depends on machinery use and less human labor.

Table 6. Energy used from different sources in greenhouse cucumber production.

Sources	Inorganic (T_1)		Organic (T_2)		Integrated (T_3)	
	(MJ ha^{-1})	(%)	(MJ ha^{-1})	(%)	(MJ ha^{-1})	(%)
Human	1884.1	2.1	1848.5	2.2	1939.6	2.1
Plant	9.0	0.01	9.0	0.01	9.0	0.01
Machinery and tractor	18485.72	20.7	16273.17	19.2	18918.9	20.2
Plastic	900.0	1.0	900.0	1.1	900.0	1.1
Diesel	3445.8	3.9	3958.1	4.7	4008.1	4.3
Electric	573.5	0.6	570.2	0.7	570.2	0.6
Irrigation water	3672.0	4.1	3366.0	4.0	3570.0	3.8
Fertilizers	7201.2	8.1	0.0	-	3454.1	3.7
FYM	0.0	-	7500.0	8.8	7500.0	8.0
Spray chemical	2751.0	3.1	0.0	-	2603.3	2.8
Wood	14137.2	15.8	14137.2	16.6	14137.2	15.1
Greenhouse structure	36169.4	40.5	36169.4	42.6	36169.4	38.6
Total	**89226.9**	**100**	**84935.6**	**100**	**93631.8**	**100**

Table 7. The physical inputs, outputs and their energy equivalents for cucumber production under different fertilizer options.

Energy type	Inorganic (T_1)		Organic (T_2)		Integrated (T_3)	
	MJ ha^{-1}	(%)*	MJ ha^{-1}	(%)*	MJ ha^{-1}	(%)*
Direct energy[a]	10475.4	11.7	10642.8	12.6	10988.0	11.7
Indirect energy[b]	28446.9	31.9	23782.2	28.1	32485.2	34.6
Renewable energy[c]	5565.1	6.2	12723.5	15.0	13018.6	13.9
Non-renewable energy[d]	46594.4	52.2	34938.7	41.2	43691.7	46.6

* Indicates percentage of total input energy
[a] Direct energy includes human, diesel, plastic, electricity and irrigation water energies.
[b] Indirect energy includes fertilizer, spray, FYM, plant and machinery & tractor energies.
[c] Renewable energy includes human, FYM, plant and irrigation water energies.
[d] Non-renewable energy includes diesel, spray, fertilizer, machinery and electric energies.

Economic analysis: The total cost of production per hectare was calculated as 4513.58 $, 4682.18 $ and 5056.90 $ for the inorganic, organic and integrated greenhouse cucumber production systems, respectively (Table 8). The ratio of total variable cost to total fixed cost were measured as 1.0, 1.1 and 1.3 in three different treatment systems, respectively. It indicated more than half of the production cost was constituted by variable cost in greenhouse cucumber farming. The results are in line with previous studies who reported that the variable costs are higher than fixed costs in greenhouse cropping system (Yelmen *et al*., 2019; Pellegrini and Fernández 2018; Sami and Rehani, 2015; Taki *et al*. 2012). Moreover, the high construction cost of greenhouse was the main reason for high production cost while higher crop productivity is the main factor for adaptation of greenhouse production system.

The gross return (output) value of the production was calculated by multiplying the cucumber yield and straw yield by their respective prices. All the prices were collected in local currency in Pakistan rupees (PKR as Rs) and then converted into international currency American dollar (USD as $) by multiplying with conversion factor as 1USD = 125 PKR. The conversion factor is the average of currency exchange rate during fiscal year 2017 to 2019. The gross output values were found 29641.5, 28237.5 and 39192.5 \$ ha^{-1} for the inorganic organic and integrated greenhouse cucumber production systems, respectively. The gross profit value was calculated by subtracting total variable cost from gross output value and it was found as 27360.92, 25788.33 and 36368.60 \$ ha^{-1} for T_1, T_2 and T_3 treatments, respectively. It is mandatory to obtain a net income in an enterprise; gross profit value must be higher than the fixed costs. According to the research results, the gross output values were found higher than fixed costs.

Table 8. Production cost items and economic analysis of greenhouse cucumber production.

Cost items (\$ ha^{-1})	**Inorganic (T_1)**	**Organic (T_2)**	**Integrated (T_3)**
Human labor	1200.375	1178.875	1237
Diesel & lubrication	82.50	78.30	82.00
Nursery	215	200	205
Fertilizer and Pesticides	400	0	300
Water and Electricity	247.8	232.1	240
Farmyard manure	0	625	625
Wood	49.9	49.9	49.9
Repair maintenance costs	85	85	85
Total variable costs (\$ ha^{-1})	**2280.58**	**2449.18**	**2823.90**
Greenhouse depreciation	351	351	351
Machinery depreciation	76	76	76
Interest on greenhouse	510	510	510
Interest on machinery	204	204	204
Land rent	833	833	833
Machinery housing	69	69	69
General overhead costs	190	190	190
Total fixed costs (\$ ha^{-1})	**2233**	**2233**	**2233**
Total production costs (\$ ha^{-1})	**4513.58**	**4682.18**	**5056.90**
Total return (\$ ha^{-1})	**29641.50**	**28237.50**	**39192.50**
Net return (\$ ha^{-1})	**25127.93**	**23555.33**	**34135.60**
Benefit/Cost ratio (BCR)	**6.57**	**6.03**	**7.75**

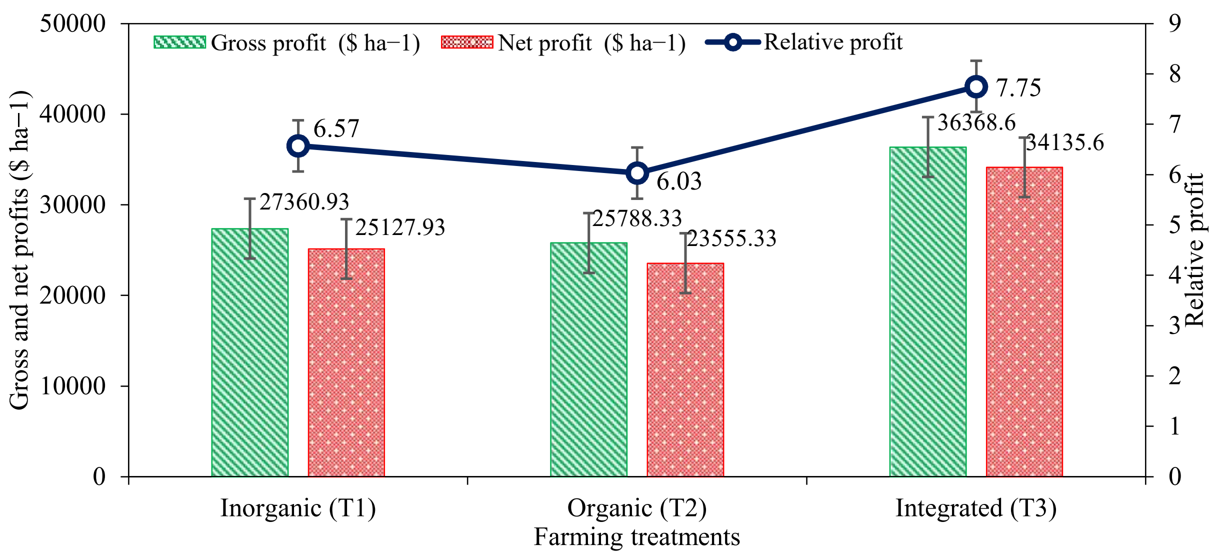

Figure 2. Calculation of profits of cucumber production under different farming treatments

The net profile was found by subtracting the production costs from gross output values and it was calculated as 25127.93, 23555.33 and 34135.60 \$ ha^{-1} for the inorganic, organic and integrated fertilizer production of cucumber in greenhouse, respectively (Table 9). The results showed that the relative profit values for the greenhouse production was 6.57, 6.03 and 7.75 in three production systems, respectively. According to economic analysis results, the cucumber farming in greenhouses under three selected treatments proves to be a profitable agricultural activity and it is more profitable if using integrated fertilization. In the previous studies conducted to determine profitability of cucumber crops under greenhouse farming the relative profit was determined as 1.68 (Mirasi *et al*., 2015), 1.79 (Taki *et al*. 2012), 2.70 (Sami and Rehani, 2015).

Conclusion: The present study evaluated the yield, energy and economic analysis of greenhouse cucumber production under different farming treatments such as inorganic, organic and integrated fertilization application. The results indicated that the output energy is more than input energy utilization. Energy use efficiency were calculated as 4.19, 4.84 and 4.87 in inorganic, organic and integrated treatment systems, respectively. The energy analysis also explored the different energy ratios are good in all treatments. The energy budgeting (energy use efficiency > 1; energy productivity > 1; specific energy < 1; and net energy > 0) implies that the cucumber cultivation under greenhouse system is feasible but higher cucumber yield under integrated fertilizer treatment make the greenhouse cucumber production more feasible and adoptive. Among the different energy utilizing sources, the greenhouse structure, agricultural machinery, tractor and wood energies were calculated highest and accounts approximately 75% of the total energy utilization. The economic analysis in term of relative profits were calculated as 6.57, 6.03 and 7.75 under inorganic, organic and integrated greenhouse production. According to economic analysis results, the cucumber farming in greenhouse proved profitable agricultural activity and it is more profitable if using integrated fertilization treatment. The energy and economic analysis revealed that cucumber production in greenhouse under integrated fertilizer treatment seemed more profitable.

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