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RESEARCH PAPER

Evaluation of energy use efficiency for greenhouse cucumber production in Barka, Oman

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تحليل كفاءة إستخدام الطاقة لإنتاج محصول الخيار في بركاء، عُمان

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Abstract. Sustainable agricultural production can be assessed through energy-use efficiency (EUE). This paper aims to evaluate the EUE for cucumber greenhouse production in Oman. Data were obtained through face to face interview with farmers. Results indicated that total energy inputs (e.g. electricity, water, fertilizers and chemicals) and total energy output (cucumber yield) were 1171.637 GJ ha^{-1} and 89.943 GJ ha^{-1}, respectively. The highest energy input in the greenhouse production was electricity, consuming 88% of total energy input. Electricity had the highest impact in cucumber greenhouse production and 99% of this electricity goes to cooling the greenhouse. When all energy inputs were classified into their different forms; direct (D) and indirect (ID), and renewable (R) and non-renewable (NR), the highest portion of total energy forms in greenhouse cucumber production was for D and NR energy. The EUE and energy productivity (EP) were found to be 0.08 and 0.10 ton GJ^{-1}, respectively. The energy use in greenhouse cucumber production was found to be inefficient and solar energy needs to be considered to improve the sustainable cucumber greenhouse production in Oman.

Keywords: Energy-use-efficiency; cucumber; greenhouse; energy productivity; energy forms.

المستخلص: يمكن تقييم الإنتاج المستدام للزراعات المحمية من خلال تحليل كفاءة إستخدام الطاقة، تهدف هذه الدراسة إلى تقييم كفاءة إستخدام الطاقة في البيوت المحمية المزروعة بمحصول الخيار في سلطنة عمان، تم الحصول على البيانات عن طريق إجراء مقابلات مع المزارعين (وجها لوجه)، وأوضحت النتائج إن الكمية الإجمالية للطاقة المستخدمة والناتجة من البيوت المحمية وصلت الى 1171.637 و 89.943 (جيجاجول/هكتار)على التوالي، وتعد الكهرباء أكبر مدخلات البيوت المحمية المستهلكة للطاقة حيث يقدر إستهلاكها للطاقة بمعدل 88% من إجمالي الطاقة المستخدمة، لذلك تعد الكهرباء أكبر العوامل المستهلكة للطاقة وقد وجد أن معظم الكهرباء يتم إستهلاكها في تبريد البيوت المحمية، وعندما تم تقسيم الطاقة إلى أنواعها الأربعة وهي الطاقة المباشرة والغير مباشرة والمتجددة والغير متجددة، وجد أن الطاقة المباشرة والغير متجددة هي أكبر أنواع الطاقة المستخدمة في البيوت المحمية، كما توصلت النتائج إلى أن كفاءة استخدام الطاقة وانتاج الطاقة من البيوت المحمية وصلت الى0.08 و 0.01 (طن/ جيجاجول)على التوالي، وفي الختام فإن كفاءة استخدام الطاقة في البيوت المحمية غير فعالة، ومن أجل تحقيق الإستدامة في الزراعة المحمية، فإنه ينصح بإستخدام الطاقة الشمسية لإنتاج الطاقة التي يحتاجها البيت المحمي.

الكلمات المفتاحية: كفاءة إستخدام الطاقة، الخيار، البيت المحمي، إنتاجية الطاقة، أنواع الطاقة.

Introduction

Greenhouses provide higher production and more efficient water consumption in comparison to open-field cropping (Abdel-Rahman and Abdel-Magid 1993; MAF 2009). As a result, the number of greenhouses in Oman was increased 5 times between 2003-2015 (Al-Ismaili et al. 2017). Cucumber (*Cucumis sativus* L.) is the most commonly grown greenhouse vegetable worldwide (Mohammadi and Omid 2010; Omid et al. 2011) and this is also the case in Oman where more than 90% of greenhouses are used for cucumber cultivation (MAF 2013). This could be attributed to its fast growth, and good nutritional and economic value (Al-Kiyoomi 2006; Al-Sadi et al. 2010). Although greenhouses provide high yield, they also require high energy consumption to achieve this yield (Bolandnazar et al. 2014; Heidari and Omid 2011).

Energy-use efficiency (EUE) is considered one of the most important factors contributing to agricultural sustainability (Firoozi et al. 2014). Such energy analysis helps in managing greenhouse production system by identifying the wasteful energy parameters and proposing management approaches (Bolandnazar et al. 2014). EUE in greenhouse production has been used by many researchers to assess greenhouse cropping systems (Hamedani et al. 2011; Taki et al. 2013). For instance, Mohammadi and Omid (2010) investigated the EUE of greenhouse cucumber production. Results revealed that cucumber production consumed 148.836 GJ ha^{-1} of the total energy input and diesel fuel was found to be the main energy consuming factor. In another study, Heidari and Omid (2011) investigated the EUE (output-input ratio) for cucumber and tomato greenhouse production. Results indicated that the EUE was 1.48 and 0.69 for

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Table 1. The energy equivalents correspond to each inputs and output use in greenhouse cucumber production.

Inputs and output (unit)	Energy equivalent (MJ Unit^{-1})	Reference
Inputs:		
Human labour (h)	1.96	(Taki et al., 2013)
Machinery (h)	13.06	(Mohammadi and Omid 2010; Ozkan et al. 2007)
Chemical fertilizers (kg):		
Nitrogen (N)	66.14	(Mohammadi and Omid 2010; Shrestha 1998)
Phosphate (P_2O_5)	12.44	(Mohammadi and Omid 2010; Shrestha 1998)
Potassium (K_2O)	11.15	(Mohammadi and Omid 2010; Shrestha 1998)
Calcium	1.12	(Mohammadi and Omid 2010)
Micro	120.00	(Banaeian et al. 2011; Mohammadi et al. 2008)
Manure (kg)	0.3	(Mohammadi and Omid 2010)
Chemicals (kg)	120.00	(Mohammadi and Omid 2010)
Water (m^3)	1.02	(Mohammadi and Omid 2010; Mousavi-Avval et al. 2011)
Electricity (kWh)	11.93	(Hatirli et al. 2005; Mousavi-Avval et al. 2011)
Seeds (kg)	1.00	(Mohammadi and Omid 2010)
Outputs:		
Cucumber (kg)	0.8	(Mohammadi and Omid 2010)

tomato and cucumber, respectively which reflected an inefficient energy use in cucumber greenhouse production. Diesel fuel was also the major contributing factors for both cucumber and tomato production (Mohammadi and Omid 2010). In strawberry greenhouses a total energy of 805.380 GJ ha^{-1} were consumed (Banaeian et al. 2011) and diesel fuel was the major energy depleting factor with 78% of the total energy. It appears thus that diesel fuel is the major variable influencing the EUE of greenhouse production.

In these studies, diesel fuel was mainly used to power heaters to provide temperature suitable growing environment. In Oman, where weather conditions are generaly hot, heaters are not necessary but cooling systems (generally fan-pad evaporative cooling systems) are used instead. In such conditions, EUE of cooled greenhouses needs to be evaluated. Therefore, this study aimed to investigate the EUE of evaporative-cooled greenhouse systems in Oman using major energy performance indicators for instance EUE, energy productivity (EP) and net energy (NE).

Table 2. The statistical summary of energy inputs (GJ ha^{-1}) and output (ton ha^{-1}) for cucumber production.

Inputs (unit)	Mean	SD	Min	Max
A. Inputs (GJ ha^{-1})				
Human labour	7.110	3.653	1.372	14.112
Machinery	1.221	0.496	0.560	1.959
Chemical fertilizers	62.582	55.535	18.793	180.802
Manure	0.008	0.004	0.000	0.015
Chemicals	5.775	3.370	1.714	10.971
Water	6.323	2.499	2.463	9.748
Electricity	1025.352	360.885	557.157	1550.185
Seeds	0.001	0.000	0.001	0.001
B. Output				
Cucumber (ton ha^{-1})	98.937	28.321	58.583	149.349

Table 3. Amount of inputs and output in cucumber production.

Inputs (unit)	Quantity per unit area (ha)	Total energy equivalent (GJ ha^{-1})	Percentage (%) of total energy	SD*
A. Inputs				
Human labour (h)	3627.454	7.110	0.607	3.653
Machinery (h)	93.464	1.221	0.104	0.496
Chemical fertilizers (kg):	2035.497	59.847	5.108	38.179
Nitrogen	609.533	40.315	3.441	
Phosphate (P_2O5)	610.364	7.593	0.648	
Potassium (K_2O)	752.171	8.387	0.716	
Calcium	34.143	0.038	0.003	
Micro	29.286	3.514	0.300	
Manure (kg)	20535.714	6.161	0.526	3.239
Chemicals (kg)	48.129	5.775	0.493	3.370
Water (m^3)	6199.506	6.323	0.540	2.499
Electricity (kWh)	85947.357	1025.352	87.514	360.885
Seeds (kg)	0.857	0.001		0.000
Total energy input (GJ ha^{-1})		1171.637	100.000	
B. Output				
Cucumber (ton ha^{-1})	112.429	89.943	100.000	32.180
Total energy output (GJ ha^{-1})		89.943		

** Represents the standard deviation of energy inputs (GJ ha^{-1}) and energy output (ton ha^{-1})*

Materials and Methods

Data were collected through a survey of 8 cucumber greenhouses farmers in Barka region, Sultanate of Oman who agreed to participate in the survey. Cucumber is the most cultivated crops in greenhouses.

Data were obtained through face to face interviews of the farmers which encompassed questions related to all expenses related to the greenhouses for three months (seeding-to-harvesting) during the cropping season (summer 2017).

The greenhouses were Quonset with polyethylene covering and fan-pad evaporative cooling system (Fig. 1). All greenhouses were of similar type, covering material and cooling system. The standard dimensions of greenhouses were 0.035 ha. The average row and plant spacing were 133 cm and 50 cm, respectively. Cucumber plants were trained to grow vertically in the greenhouse (Fig. 2). The average ambient temperature was around 29°C during the study period.

The 8 inputs considered in this study were human labor, machinery, chemical fertilizers chemicals, manure, electricity, water for irrigation and seeds and the single output was yield. The selection of the inputs was based similar studies from which we omitted diesel fuel which is not used in the greenhouses surveyed (Mousavi-Avval et al. ,2011; Mohammadi and Omid 2010 ; Omid et al. 2011).

For energy performance analysis, all inputs and output were converted into single energy unit, with conversion values obtained from different sources (Table 1). EUE, EP and NE were calculated using Equations 1-3, respectively (Mohammadi et al. 2008; Ozkan et al. 2011).

EUE = Energy Output (GJ ha^{-1})/Energy Input (GJ ha^{-1}) (Eq. 1)

EP = Cucumber Output (kg ha^{-1})/Energy Input (GJ ha^{-1}) (Eq. 2)

NE = Energy Output (GJ ha^{-1})–Energy Input (GJ ha^{-1}) (Eq. 3)

In general, the energy inputs used in agricultural production systems are classified into direct (D) and indirect (ID), and renewable (R) and non-renewable (NR) energies (Mohammadi et al. 2010; Mohammadi et al. 2008). The direct energy inputs involve human labour, water, and electricity, the indirect energy involves seeds, fertilizers, manures, chemicals, and machinery, the renewable energy inputs includes human labour, seeds, manure and water and the non-renewable energy accounts for chemicals, fertilizers, machinery and electricity.

Results and Discussion

The descriptive summary of inputs used for cucumber production and output are presented in Table 2. There

Figure 1. Quonset greenhouse with polyethylene covering and (a) fan-(b) pad evaporative cooling

Figure 2. The greenhouse vertical cultivation

were variations among inputs and output which implied that there was a potential efficiency improvement for cucumber greenhouse farmers. Thus, EUE of greenhouses was evaluated hereafter.

The inputs with their equivalent energy values consumed in cucumber production for the studied greenhouses are illustrated in Table 3. Average yield was 112.428 ton ha^{-1} which is equivalent to a total energy output of 89.943 GJ ha^{-1}. Results also revealed that 1171.637 GJ ha^{-1} of total energy input were needed in the production of cucumber crop. Electricity, chemicals and chemical fertilizers were calculated as 1025.352, 5.775 and 59.847 GJ ha^{-1}, respectively. Among all energy inputs, electricity was the highest energy consuming factor with a total of 88% (Fig. 3). This high electricity consumption was further analyzed and the analysis revealed that most of this electricity was consumed by the cooling system (Fig. 3) as the temperature sometimes exceeds 50°C (Al-Ajmi and Abdel-Rahman 2001; Al-Sadi et al. 2011). To limit this use of non-renewable energy, it is recommended to investigate the use of alternative power sources such as solar energy to operate the cooling system (fans and pumps).

Table 5. Energy use efficiency in cucumber production in Oman.

Items	Unit	Value	SD
E_{input}	GJ ha^{-1}	1171.64	374.58
E_{output}	GJ ha^{-1}	89.94	25.75
Yield	ton ha^{-1}	112.43	32.18
EUE	unitless	0.08	0.03
EP	ton GJ^{-1}	0.10	0.04
NE	GJ ha^{-1}	-1081.69	361.78

The EUF, EP and NE of cucumber production were 0.08, 0.10 tons GJ^{-1} and -1081 GJ ha^{-1} respectively (Table 5). In the literature, the EUE for greenhouse cucumber production was considered inefficient when it equals to 0.017 (Zarini et al. 2013) or even as high as 0.64 (Mohammadi and Omid 2010). Therefore, the EUE of the surveyed greenhouses in this study was (0.08) should also be considered inefficient. This EUE in cucumber greenhouse production could be increased by either increasing crop yield or by decreasing inputs consumption. The average EP (0.10 ton GJ^{-1}) for greenhouse cucumber production was lower than the reported values of 0.80 (Mohammadi and Omid 2010), 0.55 (Heidari and Omid 2011) and 0.50 (Omid et al. 2011). This indicates that every kilogram of cucumber in the surveyed greenhouses in Oman consumed 5-8 times more input energy than the greenhouses cited above. The high negative value of NE (-1081.690 GJ ha^{-1}) indicates that energy being lost in cucumber production. This can be attributed to the high electricity consumption consumed by the cooling systems. In Iran, Omid et al. (2011) and (Bolandnazar et al. 2014) found that the NE for greenhouse cucumber production gave also negative values (-55.553 and -149.317 GJ ha^{-1}, respectively) due to the high fuel consumption for heating (more than 50% of the total inputs energy). Since, energy consumption for temperature adjustment (heating or cooling system) is the highest among all inputs in greenhouse cucumber

Table 4. Energy forms (D, ID, R and NR) in cucumber production in Oman.

Form of energy	Energy value (GJ ha^{-1})	% of total energy input
D [a]	1038.785	88.66
ID[b]	73.005	6.23
R [c]	19.595	3.32
NR[d]	1092.20	93.219
Total energy input	1171.637	100.00

a -involves human labour, water, electricity.
b -involves seeds, fertilizer, manure, chemicals, machinery.
c -involves human labour, seeds, manure, water.
d -involves chemicals, fertilizer, machinery, electricity.

Figure 3. The The percentage energy (GJ/ha^{-1}) inputs used in cucumber production and the percentage of irrigation and cooling from the total electricity

production; the existing heating/cooling systems need improvement in order to achieve a more efficient energy use and sustainable crop production.

The percentage of total energy inputs as D, ID, R and NR energy is shown in Table 4. It was found that the D energy inputs (e.g. human labour, water, electricity) followed by NR energy inputs (e.g. chemicals, fertilizer, machinery, electricity) were the highest energy consumers and the R energy forms (e.g. human labour, seeds, manure, water) were the lowest energy consumers. Other investigators, such as, Ozkan et al. (2007), Kizilaslan (2009), Mohammadi and Omid (2010), Banaeian et al. (2011) and Zarini et al. (2013) reported similar outcomes.

The tetra-inoculum (Tm+Tc+Gr+Gn) reported highest average of dry weight of plants which was 710 mg/plant compared with negative and positive control which was 86 and 479 mg/plant respectively, followed by the treatment of tri-inoculum (Tc+Gr+Gn) which was 602 mg/plant. The combined application of Gr+Gn exhibited significant increase in the dry weight of plant which was 559 mg/plant. Tariq and Magee (1990) found that volatile components of garlic extracts inhibited germination of the microconidia, macroconidia and mycelium of the *F. oxysporum* f. sp. *lycopersici in vitro*. Al-Rahmah et al. (2013) has been found that ginger extracts has strong fungistatic and fungicidal activities against *F. oxysporum* and *Pythium aphanidermatum* with minimal inhibitory concentration. Furthermore, Sahar et al. (2013) proved that foliar application of Topsin-M with concentration of 0.1 % was significantly reduced the disease incidence of Fusarium wilt disease on eggplant.

Conclusion

This study investigates the EUE of greenhouse cucumber production. Results revealed that the total energy output for greenhouse cucumber production was 12 times lower than the total energy inputs. The EUE in greenhouse cucumber production was inefficient and electricity was the major energy consuming factor. Fan-pad evaporative cooling system was the major consumer of the electricity and thus the existing cooling systems need be improved to achieve better efficient energy. Highest energy form in greenhouse cucumber production was the NR energy. Special attention has to be given to this form of energy in order to achieve sustainable cucumber production. Solar energy needs to be exploited to improve the sustainable cucumber greenhouse production in Oman.

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