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Evaluation of Greenhouse Cropping Systems in Oman

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Abstract: *This study presents a preliminary trial to evaluate the performance of greenhouse cropping systems in Oman using five performance indicators; land-use efficiency (LUE), water-use efficiency (WUE), irrigated-water-use efficiency (IWUE), gross-water-use efficiency (GWUE) and energy-use efficiency (EUE). Three cucumber greenhouses were chosen as case studies. The first greenhouse was in Suwaiq city (SGH), the second greenhouse was in Thumrait city (TGH) and the third greenhouse was representing greenhouse systems in Al-Batinah governorates (BGH). Necessary data to perform the calculations of performance indicators were collected from the three greenhouses. We found that Thumrait greenhouse (TGH) had the highest LUE (181405 kg/ha) compared with Al-Batinah greenhouses (BGH) and Suwaiq greenhouse (SGH) (156695 and 142450 kg/ha, respectively). Similarly, WUE was the highest in TGH (49.2 kg/m^3) and lowest in SGH (38.6 kg/m^3) because the latter had the highest water consumption for irrigation. Correspondingly, TGH had the highest IWUE (673.4 kg/m^3) in comparison to BGH (381.9 kg/m^3) and SGH (323 kg/m^3). On the other hand, BGH had the lowest GWUE (159.9 kg/m^3) because it had the maximum water consumption for cooling. SGH had the highest EUE (0.34) followed by TGH (0.21) and BGH (0.15). From above, it is misleading to use a single performance indicator to describe the overall performance greenhouse cropping systems because one greenhouse could be strong in one indicator and weak in others. However, because energy-use efficiency (EUE) includes all input and output variables that are incorporated with other indicators, it is highly recommended to use it as a holistic performance indicator of greenhouse systems.*

Keywords: *Greenhouse performance, land-use, water-use, energy-use efficiency*

INTRODUCTION

The agricultural development is one of the main sectors in the economic development of many countries. One of the processes that accelerate the agricultural development is the use of Controlled Environment Agriculture (CEA) facilities. CEA is the planting of vegetables, ornamentals and other plants in enclosed facilities where the environmental factors are modified, time-programmed and carefully-controlled in order to enhance the plant growth, maturation and productivity (Fogg *et al.*, 1979). CEA, particularly greenhouses, is a major contributor of agricultural production. In Oman, it was found that greenhouse cultivation increased land productivity by approximately 12 times in comparison with open field agriculture (Tawfiq and Al-Kaefi, 2009). Similarly, water productivity in greenhouse was more than in open field cultivation by almost double for two specific crops; cucumber and tomatoes (MAF & ICARDA, 2011). Due to these advantages, the number of greenhouses in Oman increased from 782 in 2001 to 2491 in 2008 (Tawfiq and Al-Kaefi, 2009) and in 2010, it reached 4740 (MAF & ICARDA, 2011). However, evaporative cooling systems used in greenhouses under arid weather conditions require approximately 58% of the total water consumption and 98% of the total electricity usage (Fadel *et al.* 2014). Another study reported that water consumption in the evaporative cooler alone can

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reach be as high as 67% of the total water consumption (Al-Mulla, 2006).

Water and energy are essential in food production such that, water requires energy for pumping, treating and transporting, and energy needs water during generation (Daher and Mohtar, 2015). There is a growing awareness about the nexus between food, water and energy as they are highly interconnected (Rasul, 2014). Therefore, when considering the effectiveness of agricultural systems, these three components have to be considered together. Therefore, the evaluation of greenhouse cropping system has to take into consideration water, energy and land use efficiencies as they significantly influence the overallperformance of greenhouse systems.

There are several terms used to quantify the performance of greenhouse growing systems. Land use efficiency(LUE), also known as yield or productivity, is measured as the weight of the crop production per unit area in any particular year (Quaye *et al.* 2010).Water use efficiency (WUE), on the other hand, is defined as the yield (kg) per unit area (hectare), per crop evapotranspiration rate (ET) (mm) (Fischer *et al.*, 2014). Crop water productivity (CWP) is another term defined as crop yield (kg/ha) per amount of evapotranspiration (mm), which is identical to the term WUE (Zwart and Bastiaanssen, 2004). Additionally,irrigated water use efficiency (IWUE) is the yield production (kg) per unit volume of irrigation water (m^3) (Fan *et al.*, 2014). However, land and water useefficiencies when considered separatelyprovide a missing picture on the overall performance of the greenhouse cropping system. For instance, a given greenhouse with very good WUE or IWUE could be associated with extremely high energy consumption. So, the WUE alone, which is widely used, could be misleading as it omits the influence of other factorsaffecting the total greenhouse productivity such as the large quantities of non-commercial energies (manureand seeds energies) and direct or indirect commercial energies (electricity, diesel, pesticides, fertilizer, machinery, irrigation water) (Taki *et al.*, 2012). The utilization of commercial and non-commercial energies efficiently helps to enhance the agricultural productivity and profitability of greenhouses. Therefore, the energy use efficiency (EUE) is another term that could be used to describe the energy efficiency (or inefficiency) of a particular agricultural system (Unakitan *et al.*, 2010). EUE is the ratio of energy inputsto the output food energy.

This study presents the first trial to evaluate the performance of greenhouse cropping systems in Oman. The overall aim of this study is touse LUE, WUE, IWUE, GWUE and EUE in order to assess the current efficiency of greenhouse cropping systems and to find the most representative term that provides a comprehensive understanding of the performance of greenhouse cropping systems.

METHODOLOGY

Selection of Case Study Farms

In this study,data were collected from three greenhouses in Oman. One of these greenhouses is located in Suwayq city (SGH), the second greenhouse is in Thumrait city (TGH) in Dhofar Governorate (TGH), and the data of the third greenhouse was obtained from Al-Batinh Farmer Association (BGH). All greenhouses were planted with cucumber crop during the Spring season (i.e. September to December). Cucumber-cropped greenhouses were chosen because almost 90% of the greenhouses in Oman are used for cucumber production while only 5-9% of greenhouses are used for tomato production (MAF & ICARDA, 2011).

Data Collection

The data were collected from greenhouse farmers, by using a single visit assistant interview (face-to-face) questionnaire and also field measurements. The collected data included the input information necessary to calculate the five performance indicators; LUE, WUE, IWUE, GWUE and EUE. These data included the following points:

- Greenhouse type and dimensions
- ET measurements
- Irrigation water consumption
- Cooling water consumption
- Seeds quantity and cost

- Number of labors and number of working hours
- Type of machineryused and number of working hours
- Cost of operating or renting machinery
- Types of fertilizers and quantity
- Types of chemicals and quantity
- Electricity cost (for ventilation, cooling and irrigation)
- Duration of season (from planting to the ends of harvesting)
- Total yield produced per season

Calculation of efficiencies

Land-use Efficiency (LUE) is calculated as follows (Quaye *et al.,* 2010):

$$LUE = Y/A \quad [\text{kg ha}^{-1}] \qquad (1)$$

Where Y is the yield (kg) and A is the cultivated area (ha).

Water use Efficiency (WUE) is the term used to indicate the amount of agricultural products (kg) in relation to the amount of water used (m^3) to produce the end products (Fan *et al.,* 2014). WUE can be calculated by using the flowing equation:

$$WUE = Y/ET \quad [\text{kg m}^{-3}] \qquad (2)$$

Where Y is the crop yield (kg m^{-2}) and ET is evapotranspiration depth (m) which can be calculated using the following equation (Allen *et al.,* 1998):

$$ET = ET_o x K_c \quad [\text{mm}] \qquad (3)$$

Where K_c is the crop coefficient factor obtained from literatures and ET_o is reference evapotranspiration (mm day^{-1}) can be obtained through Penman-Monteith or Pan evaporation equations (Allen *et al.,* 1998).

Irrigation water use efficiency (IWUE) is the yield production (kg) per unit volume of irrigation water (m^3) (Fan *et al.,* 2014):

$$IWUE = Y/I \quad [\text{kg m}^{-3}] \qquad (4)$$

Where Y represents the crop yield production (kg) and I indicates the amount of irrigation water used (m^3). The total water use efficiency inside the greenhouse can be obtained from the gross water use efficiency (GWUE) which can be calculated from:

$$GWUE = Y / (I + CW) \quad [\text{kg m}^{-3}] \qquad (5)$$

Where Y is the crop yield production (kg), I is the amount of irrigation water used (m^3) and CW is the water used in the cooling system (m^3).

Zahedi *et al.* (2015) defined the Energy-use efficiency (EUE) as the ratio between energy output and energy input based on the energy equivalents of the inputs and outputs (Table 1). EUE can be calculated as (Taki *et al.,* 2012):

$$EUE = Energy\ outputs / Energy\ Inputs \qquad (6)$$

Where energy inputs (MJ ha^{-1}) represents the sum of all energy equivalents for human labor, machinery, diesel fuel, chemical fertilizers, manure, chemical pesticides, electricity, water for irrigation and cooling and seeds. The energy output (MJ ha^{-1}) includes only the energy equivalent of the yield.

RESULTS AND DISCUSSION

The overall production of cucumber in Thumrait greenhouse (TGH), Suway q green house (SGH) and Al-Batinh Farmer Association greenhouse (BGH) were 8, 5 and 5.5 tons, respectively.

Table 2 reveals that LUE is higher in TGH (181405kg ha^{-1}) than in SGH (142450 kg ha^{-1}) and BGH (156695 kg ha^{-1}). The average cucumber yield production in Oman during winter season is 4.521 tons for a single greenhouse as reported by MAF and ICARDA (2011). This indicates that the average LUE is around 128803 kgha^{-1}. Therefore, all green houses have slightly higher LUE than the average reported value.

The ET_c value (4.1 mm/day) for cucumber crop that was measured by Al-Busaidi and Al-Mulla (2014) was used in the calculation of the water use efficiency (WUE) for all green houses in this study. As shown in Table 3, WUE was 49.16 kg m^{-3} for TGH which is the highest value compared to the other greenhouses. According to the study done by Mao *et al.* (2003), WUE values ranged from 2.79 to 98.76 kgm^{-3} of a green house cultivated with cucumber.

Table 1
Energy equivalents of different input and output values used different farming system

Inputs/outputs	*Energy equivalents (MJ/unit)*	*References*
Energy inputs		
Human labour (h)	2.3	Ozkan *et al.*, 2011; Yaldiz *et al.*, 1993
Machinery (h)	62.70	Singh *et al.*, 2002
Fertilizers (kg)		
Nitrogen	60.60	Singh *et al.*, 2002
Phosphorus	11.10	Singh *et al.*, 2002
Potassium	6.70	Singh *et al.*, 2002
Farm yard manure	0.3	Singh *et al.*, 2002
Chemicals (kg)		
Pesticides (general)	199	Helsel, 1992; Ozkan *et al.*, 2003
Fungicides	92	Helsel, 1992; Ozkan *et al.*, 2003
Herbicides	238	Helsel, 1992; Ozkan *et al.*, 2003
Seed (kg)	1	Singh *et al.*, 2002
Diesel-oil (L)	56.31	Singh *et al.*, 2002
Electricity (kWh)	3.6	Ozkan *et al.*, 2011
Water for irrigation/ cooling (m^3)	0.63	Ozkan *et al.*, 2011; Yaldiz et al., 1993
Energy outputs		
Cucumber yield (kg)	0.8	Yaldiz *et al.*, 1993

Table 2
LUE for all greenhouses

Green houses	*Yield (kg)*	*Area (ha)*	*LUE (kg/ha)*
TGH	8000	0.0441	181405
SGH	5000	0.0351	142450
BGH	5500	0.0351	156695

The irrigation water use efficiency (IWUE)values calculated in this study (Table 3) indicate that the lower the amount of irrigation water applied the higher the IWUE achieved.In BGH, around 58% of total greenhouse water use was consumed by the evaporative cooling system which is equal to the amountthat was reported byFadel et al. (2014) during winter season in UAE.However, inTGH and SGH, the evaporative cooling system consumed approximately 43% and 37% respectively. Al-Mulla, (2006) reported that the consumption of evaporative cooling systemsnormally range from33% to 67% of the total water used. The GWUE for BGH was the lowest among the other greenhouses with 159.88 kg m^{-3}as result of the high consumption of water for cooling and irrigation purposes.

Table 3
WUE, IWUE and GWUE for all greenhouses

Greenhouse	*Irrigation water (m^3)*	*Cooling water (m^3)*	*WUE (kg m^{-3})*	*IWUE (kg m^{-3})*	*GWUE (kg m^{-3})*
TGH	11.88	9.00	49.16	673.4	383.14
SGH	15.48	9.00	38.60	323	204.25
BGH	14.4	20	42.46	381.9	159.88

Figure 1 illustrates the distribution of energy inputs used in cucumber production among the three greenhouses. Electricity takes the largest part of the total energy inputs in all greenhouses with 90% in TGH, 73% in SGH and 74% in BGH. In TGH, the second highest energy input was human labor with 6% of the total energy inputs. However, the second highest input energy in SGH and BGH was the fertilizers with 16% and 20% of the total energy input which could indicate soil infertility in Al-Batinah region where both greenhouses are located.

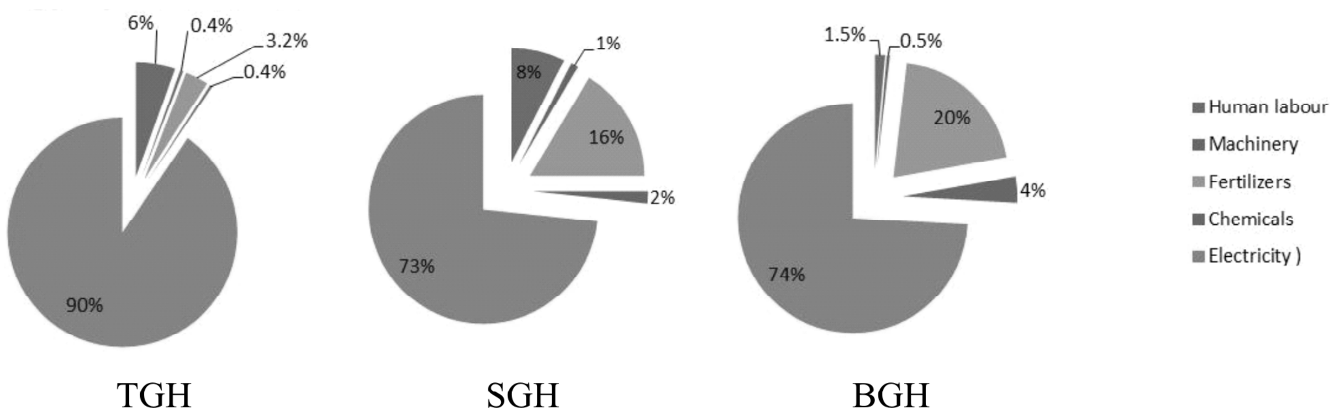

Figure 1: Distribution of energy inputs among three greenhouses

As the value of EUE increases, it indicates enhanced energy efficiency (Unakitan, *et al.*, 2010). The EUE for SGH was the highest (0.339) followed by TGH (0.214) and BGH (0.151). However, EUE for all three greenhouses is significantly less than EUE reported in literature. For the same crop under greenhouse cultivation, EUE was reported to range from 0.56 (Taki *et al.,* 2012) to 0.76 (Ozkan, *et al.,* 2004). The reason of the low EUE in the three greenhouses considered in this study could be attributed to the high use of input energies. Several factors such as increasing the crop yield, use of renewable energy and optimizationof energy inputs consumption are necessary to improve the energy use efficiency (Taki *et al.,* 2012).

From above, TGH was the highest greenhouse in LUE, WUE and IWUE which indicate the efficiency of using water and land in cucumber production. However, TGHhad lower EUE than SGH that indicate the inefficiency of using energy in this greenhouse. SGH had the highest EUE as a result of using the lowest energy especially electricity. BGH was the lowest greenhouse in IWUE and EUE and that was because of the inefficient use of water and energy.

CONCLUSIONS AND RECOMMENDATIONS

As in the case of TGH, land and water use efficiencies when considered separately provide a missing picture on the overall performance of the greenhouse cropping system. However, EUE illustrates the efficiency of using energy including all the parameters that may affect the total greenhouse productivity such as the large quantities of non-commercial energies (human power, fertilizers and seeds) and direct or indirect commercial energies (electricity, diesel, pesticides, chemical fertilizer, machinery and irrigation water).In conclusion, EUE is the most representative term that provides a comprehensive understanding of the total greenhouse cropping system.Further research is recommended to evaluate water-, land- and energy-use efficiencies under greenhouse cultivation in Oman.

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