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Water Use Efficiency and Economic Evaluation of the Hydroponic versus Conventional Cultivation Systems for Green Fodder Production in Saudi Arabia

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Abstract: The current study is aimed to assess water use efficiency and evaluate economic viability of hydroponic and conventional production of barley green fodder by keeping in view the water scarcity challenges in Saudi Arabia. A hydroponic system and open field experimental plot was used to evaluate the water use efficiency for different irrigation regimes. Economic indicators for both production systems are estimated and compared to accomplish economic assessment. Estimated indicators include returns from inputs and net profit; benefit-cost ratio; break-even levels of prices, production, and yield; returns over variable cost; and returns on investment. Results indicated that the yield of barley green fodder produced under hydroponic conditions overtopped the yield under conventional cultivation. Under hydroponic and conventional conditions, WUE was decreased with increasing the harvesting date. However, WUE for the hydroponic technique was much higher than the conventional one. The returns and net profits supported the conventional cultivation methods, where lower dry matter content coupled with higher fixed and variable costs incurred by the hydroponic technique outweighed returns leading to economic loss. Cost-benefit ratios, returns over investment, and break-even prices and yield suggested that growing barley fodder under the hydroponic technique is economically not suitable for small-scale farming. However, regarding water conservation, hydroponic barley cultivation showed superiority over conventional field cultivation. Further research on the adoption of hydroponic fodder cultivation is highly recommended for water-scarce arid regions, such as the Kingdom of Saudi Arabia.

Keywords: barley green fodder; break-even; cost-benefit ratio; water conservation

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1. Introduction

Water resources in the Kingdom of Saudi Arabia (KSA) are scarce and limited, while their uses are subjected to an extreme hot and very dry environment [1]. Despite the water scarcity in the KSA, the annual total water consumption, which is extracted mostly from groundwater, increased from 17.79 billion m^3 in 2008 to nearly 23.83 billion m^3 in 2018 [2]. Overall, approximately 70% to 80% of water is consumed by the agricultural sector. Green fodder production, whether from alfalfa or barley crops, is mainly responsible for depleting groundwater resources because it consumes approximately 67% of the water used for the agricultural sector irrigation [1]. Green fodder is one of the vital fodder resources for the livestock in Saudi Arabia, with nearly 13.5 million heads [3]. Due to the ban on green fodder as crop cultivation, the planted area under green fodder crops tremendously reduce area and ultimately fodder production [4]. The economic evaluation indicated that the ban on fodder cultivation, in ground water savings, worth 1.4 billion USD, while the production cost was 1.34 billion USD. Accordingly, the benefit-cost ratio was 1.22, so the net present value was 0.3 billion USD. Therefore, the decision of banning cultivation of the green fodder crops was in the interest of the KSA [5].

Addressing the problem of water scarcity in Saudi Arabia, unconventional freshwater sources including desalination and wastewater recycling are the alternate sources of water for social and economic development [6]. Growing challenges to water and food security in Saudi Arabia is the increase in per capita supply and demand for water, resulting in high values of the water scarcity index [7]. For instance, production and area under wheat cultivation in Saudi Arabia showed negative trends explained by risks associated with water scarcity [7]. Insufficient availability of fresh water is one of the major impediments to attain a viable agricultural progress in Saudi Arabia [8]. Addressing the problem of water scarcity in Saudi Arabia, unconventional fresh water sources including desalination and wastewater recycling are alternate sources of water for social and economic development [6].

Arable farming in the KSA depends largely on conventional irrigation systems such as dwindling underground water reservoirs [9]. During 1990–2009, 83–90% of the total water demands in Saudi Arabia were allocated to grow cereals, vegetables, fruits, and forage crops [10].

The KSA, similar to many other parts of the world, is facing the challenge of self-sufficiency, especially in green fodder to feed livestock. The hydroponic green fodder production technology is an innovative method using a protected and controlled environment in which seeds are germinated into high quality, nutritious, and disease-free food for livestock [11]. Availability and supply of fresh green forage throughout the year is necessary for cost-effective and sustainable dairy farming. Growing hydroponic green fodder for livestock production is gaining popularity due to limited resources for green fodder production in the Middle East, Asia, and Africa [12]. Hydroponic barley fodder production is generating prominent interest for livestock investors as a sustainable option to decrease the competition between food and feed production [13]. In comparison with conventional open-field farming, hydroponics systems have gained popularity as a vital technology for green fodder cultivation [14]. In this regard, the nutritional and economic benefits of feeding hydroponically grown maize and barley fodder for Konkan Kanyal goats revealed that feeding hydroponically cultivated maize and barley fodder for goats indicated economic viability, in addition to raising the total dry matter intake, body weight gains, and feed conversion efficiency [15].

The benefits of hydroponic cultivation of barley fodder regarding the chemical composition, food value, effect on milk production, and the economic value were studied [16]. The results showed that hydroponic cultivation can yield long-term high nutritious green feed; although, economically the technique is not profitable. In the past, pot-based soilless hybrid hydroponics was tested using a micro-climatically controlled greenhouse to show the impact on the growth, productivity, water, and nutrient efficiency for the cost-effective production of cucumber and tomato crops [17]. The break-even point of 4–5 years of the established hybrid hydroponic technology makes it economically viable and affordable technology for off-season cucumber and tomato crop production.

Management and planning of sustainable water resources in the Kingdom are required to produce crops [18]. Hence, research efforts that cover all related aspects are required for the generation and application of non-conventional water-conserving agricultural technologies to produce green fodder and vegetable crops. However, hydroponic fodder production requires in-depth and preliminary economic assessments before implementation.

Dairy farming production in the Kingdom of Saudi Arabia is at risk due to various factors [19]. These factors may include water scarcity, green fodder shortage, reduced land resources for green fodder production, salinization of range lands, high labor cost, prolonged plant growth period, and uncontrollable climatic factors [19]. Shortage of accessible water for irrigation, consequences of climate change coupled with ecological concerns generated the need to explore new methods of improving water use efficiency for agronomic crops [20]. Therefore, this study aimed at estimating water use efficiency and economic comparative assessment of barley green fodder production under the hydroponic technique and the conventional cultivation methods.

2. Materials and Methods

2.1. Hydroponic Trials

In this study, two closed re-circulating automated hydroponic units with dimensions 7.3 × 18.3 m (Figure 1) were established in a double fiber greenhouse at the Research and Training station, King Faisal University, to produce green fodder barley all year long. Each unit was equipped with an automated controlled microenvironment and solid set sprinklers. The environmental conditions were set as 16–18 h light, 18–23 °C air temperature, 1–23 °C water temperature, and 40%–80% relative humidity. To determine the optimal seeding rate for maximum forage production for barley, the seeds were grown at 2, 3, 4, 5, 6, and 7 kgm^{-2}. Harvesting was done at 7, 10, 15, 20, and 25 days from sowing to determine the best harvesting date for barley green fodder production in the hydroponic system.

Figure 1. Indoor hydroponic system for barely green fodder production.

2.2. Open Filed Trials

In open field trials (Figure 2), three irrigation regimes such as 100%, 80%, and 70% of reference evapotranspiration (ET_O) were adapted during the growing season of barley (November to April). Each irrigation regime was comprised of four replicates; the dimension of each experimental unit was 3 × 3 m, occupying an area of 36 m^2. Barley seeds (cv. Gesto) were sown at 150 kg ha^{-1} using hand drills in 15 cm apart rows. Nitrogen fertilizer was applied at 200 kg ha^{-1} in four equal portions during this experiment. The open field trails were conducted in two seasons (years), and the data of the combined analysis of the two seasons were used for analysis. All recommended cultural practices for barley production were followed.

Figure 2. Open field plot for conventionally grown barley green fodder production.

2.3. Dry Matter and Soil Moisture Contents

Dry matter and soil moisture contents of the barley green fodder were calculated by weighing 500 g by placing them in an oven for 72 h at 60 °C. After 72 h, the dry fodder was weighed and used to estimate the soil moisture contents of the fodder by using the following equation:

$$\text{\% Soil moisture} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Dry weight}} \times 100 \quad (1)$$

2.4. Cost-Benefit Analysis

Cost-benefit analysis is a powerful tool to decide whether to make a change in a decision related to a particular investment. It associates a cost with potential benefits to select the greatest overall benefit for the cost incurred [21]. The cost-benefit ratio compares projects to select the project which returns the highest cost-benefit ratio given by the following equation:

$$\text{CBR} = \frac{\text{B}}{\text{C}} \quad (2)$$

where CBR, B, and C denote cost-benefit ratio, benefits, and costs, respectively.

Benefits and costs for hydroponic and conventional systems were compared for fodder crops.

2.5. Break-Even Levels of Prices and Production

In order to determine the amount of units to be sold to cover the cost of production, the break-even analysis was used, which is the volume at which an enterprise can earn no profit, and, however, make no losses [22]. The break-even point is given by the following equation:

$$\text{BP} = \frac{\text{FC}}{\text{P} - \text{VC}} \quad (3)$$

where BP, FC, P, and VC, denote the break-even point, fixed cost, price per unit, and variable cost per unit, respectively. The difference between the market price and the variable cost per unit measures how much each item produced contributes to covering the fixed costs of the project.

Operating at the break-even point indicated that the enterprise revenue covers the cost of production (revenue is equal to cost; the profit at the break-even point is zero). Production, below or above break-even levels, indicated that the enterprise is operating at a loss or profit, respectively [23].

2.6. Returns over Variable Cost and Returns on Investment

The hydroponic greenhouse production budget using a program [24] was adjusted using fixed and variable costs incurred for the two cultivation methods to estimate returns over variable cost and returns on investment. Returns over variable cost were calculated by subtracting variable cost from total returns. In contrast, return on investment was calculated by subtracting total cost from total returns.

Returns and costs were evaluated using the current prices of fodder crops in US dollars. Total cost includes fixed and variable costs. Fixed cost is the cost of establishing the enterprise, which will be incurred even if the level of production is zero. Variable cost includes the cost of production inputs and will be incurred when the process of production starts. Gross and net returns were estimated for the production systems by subtracting variable cost and total cost out of total returns, respectively. For the calculation of fixed costs during the production period, a commonly used straight-line method was used with the following specification [25].

$$\mathrm{FC} = \frac{\mathrm{IC} - \mathrm{RV}}{\mathrm{UL}} \tag{4}$$

where FC, IC, RV, and UL denote fixed cost, initial cost, residual value, and useful life of the used asset, respectively.

The items of fixed and variable costs for barley fodder crops under the two cultivation methods are shown in the Supplementary Tables S1–S4. Both explicit and implicit costs were considered. Explicit costs indicate costs requiring a direct outlay of money, whereas implicit costs denote costs that do not entail a direct outlay of money. Hence, quantifying the opportunity cost of used resources. Because of differences in cultivated area, a square meter was used as the unit for comparisons.

2.7. Water Use Efficiency

Hydroponically, the total water use (TWU) and WUE of the barley green fodder production were determined from the total amount of water added and drained out of the trays during the course of each treatment. The TWU by barley plants (Liters/trays) was calculated according to the following equation:

$$\mathrm{TWU} = \text{total water added in irrigation} - \text{total water drained from trays}$$

Then, water use efficiency was computed from the total green fodder (TGF) produced and the TWU per tray from the following equation [26].

$$\mathrm{WUE} = \frac{\mathrm{TGF}\left(\frac{\mathrm{kg}}{\mathrm{tray}}\right)}{\mathrm{TWU}\left(\frac{\mathrm{liter}}{\mathrm{tray}}\right)} \tag{5}$$

While conventionally, the WUE was determined using the economic yield of barley green fodder (kg) and the amount of water (m^3) used to produce barley green fodder during the growing season. Then, the WUE was computed from the following equation [27].

$$\mathrm{WUE} = \frac{\text{Econmomic yield}}{\text{Water used to produce the yield}} \tag{6}$$

3. Results and Discussion

3.1. Hydroponic Barley Green Fodder

Hydroponically, the barley grains accumulated fresh weight during experimental period at all seeding rates due to continuous water imbibition in the hydroponic system (Figure 3). The fresh weight, as shown in Figure 4, increased significantly at all seedling rates (2, 3, 4, 5, 6, and 7 kg m^{-2}) as the days of the harvest cuts increased. The highest means of the fresh weight production (kg m^{-2}) as affected by the interaction between cut days and sowing rates at the 7 days of harvest cuts were observed with 22.83 and 24.96 kg m^{-2} for the seeding rates of 6 and 7 kg m^{-2}, respectively. The regression between the fresh weight production and different harvest cut days produced positive linear correlations with different coefficients of determination r^2. The seeding rate of 7 kg m^{-2} showed a high coefficient of determination with r^2 value of 0.89 (Figure 4).

Figure 3. Weekly (7-day cut) produce of hydroponic barley green fodder.

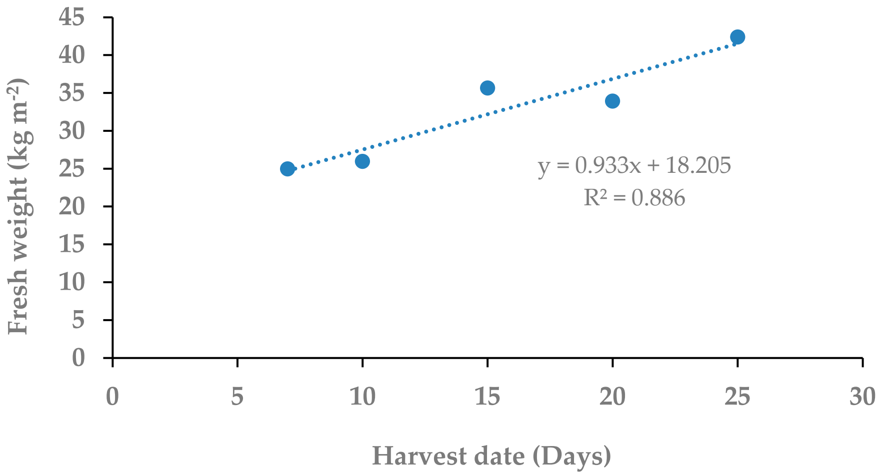

Figure 4. Relationship between fresh weight productivity (kg m^{-2}) and harvest cut days at a sowing seeding rate of 7 kg m^{-2}.

As affected by the interaction between harvest cut days and sowing seeding rates, the 6 kg m^{-2} seeding rate gave the highest daily mean dry weight productions of 542.9 g m^{-2}, 326 g m^{-2}, and 105.6 g m^{-2} at the harvest cut days of 7, 15, and 25, respectively, as shown in Table 1. Whereas, the interaction between the cut day of 7 and the seeding rate of 6 kg m^{-2} was found to be the highest, 542.9 g m^{-2}. Therefore, harvesting 7 days from the sowing date was observed to be the best harvesting date for the barley green fodder production in the hydroponic system. One way ANOVA analysis was conducted to test the difference in dry weight production of fodder under various harvesting intervals. Based on F statistic (calculated F = 6.5), results showed statistically significant difference in dry weight production between the selected harvesting intervals at $p < 0.05$ level ($F (4, 25) = 3.69$). Hence, the null hypothesis of no significant difference between groups is rejected.

Table 1. Means of dry weight production (g m^{-2} day^{-1}) as affected by the interaction between harvest cut days and sowing seeding rates.

Harvest Cut Day	2 kg m^{-2}	3 kg m^{-2}	4 kg m^{-2}	5 kg m^{-2}	6 kg m^{-2}	7 kg m^{-2}
7	197.1	288.6	348.7	487.1	542.9	397.1
10	124.0	170.0	228.0	300.0	340.0	464.0
15	199.0	181.0	243.3	266.7	326	324.0
20	49.5	78.5	160.5	277.5	366	382.0
25	30.0	41.6	62.8	74.4	105.6	98

LSD at (p = 0.05) 0.92.

3.2. Conventional Barley Green Fodder

In the open field, the dry weight production of the first treatment (80% ET_o) during the second cutting was significantly higher than the second treatment (70% ET_o) and the control (100% ET_o), as shown in Table 2. Whereas, the total dry weight production of the second treatment was non-significantly higher than the first treatment and the control.

Table 2. First and second cut dry weight (kg ha^{-1}) as well as total dry weight (kg ha^{-1}) as affected by different irrigation treatments.

Treatments	1st Cut Dry Weight (kg ha^{-1})	2nd Cut Dry Weight (kg ha^{-1})	Total Dry Weight (kg ha^{-1})
Control (100% ET_{pan})	3834.25	1400	5234.3
Treatment 1 (80% ET_{pan})	2940.41	2475	5415.4
Treatment 2 (70% ET_{pan})	3975.5	1550	5525.5
F test	NS	*	NS
LSD	–	846.2	–

3.3. Water Conservation

Water is an essential element for the growth processes of fresh barley green fodder and dry matter yield, whether produced in a hydroponic system or in an open field. In this study, the hydroponic technique was found effective to produce per square meter fresh green fodder and dry matter yield of 2.83 and 2.3 times higher than the open field, respectively. The results indicated that barley green fodder production under the hydroponic system used water more efficiently as compared to the open field. To produce 1 ton of hydroponic fresh green fodder, the barley required 2.83 m^3 of water compared to 117 m^3 for the open field. Hydroponically, WUE based on the fresh green fodder and the dry matter weight decreased with the harvesting date (Figure 5). The highest WUE obtained based on the fresh fodder weight was 411.1 kg m^{-3} and the lowest was 4.5 kg m^{-3} based on dry matter weight under the hydroponic system. However, for the open field, WUE increased with decreasing the irrigation regime (Figure 6). In the open field, the highest WUE was 8.49 kg m^{-3} based on the fresh fodder with 80% ET_O irrigation regime while the lowest was 1.9 kg m^{-3} based on the dry matter weight with the 100% ET_O irrigation regime. Therefore, WUE of the barley green fodder based on the fresh matter under the hydroponic cultivation was 48 times greater than the conventional cultivation. While based on the dry matter, it was 2.4 times greater than the conventional.

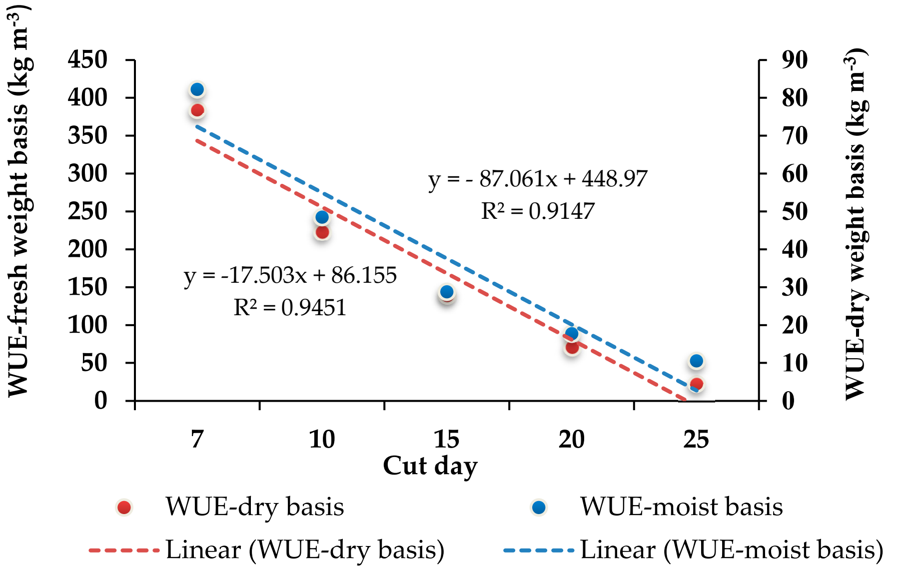

Figure 5. Water use efficiency (WUE) for hydroponic barley green fodder production.

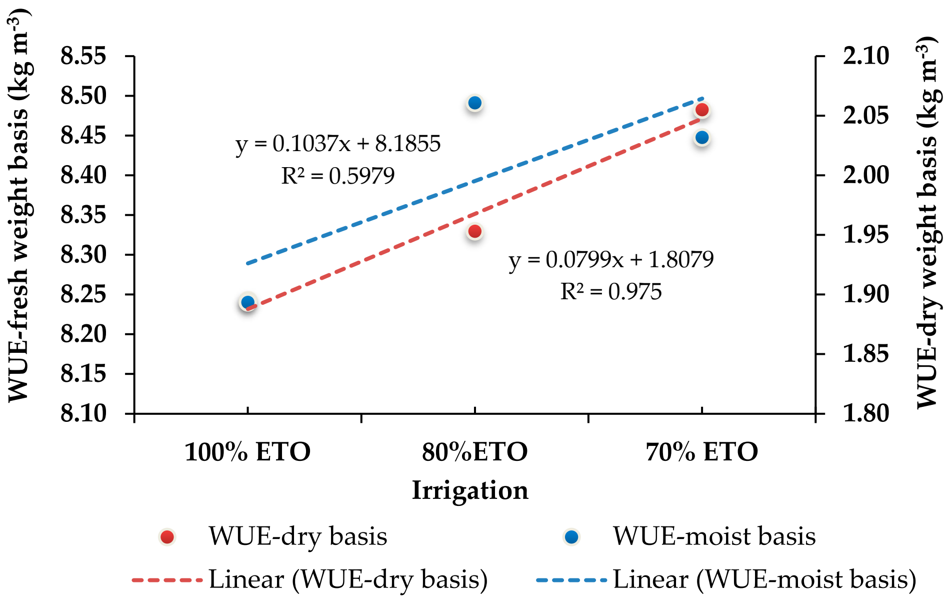

Figure 6. Water use efficiency (WUE) for conventional barley green fodder production.

3.4. Economic Outcomes

Fixed and variable costs per square meter for the conventional open field system accounts for 11.4% and 10.2% of the hydroponic system, respectively (Table 3).

The higher fixed and variable costs incurred by the hydroponic system overweighed returns resulting in a loss of 0.31 USD per square meter. Whereas, for the conventional method returns exceeded total cost (fixed and variable) resulting in a profit of 0.19 USD per square meter. The variable cost exceeded fixed cost for both methods, and the findings might be attributed to the long useful life of the fixed cost items, resulting in low depreciation value of the used assets.

The yield of fodder produced under the hydroponic cultivation system greatly exceeded the yield of fodder under the conventional cultivation system by ~7.5 folds (Table 3). Dry matter of the fodder was used for analysis and comparison. Using fresh produced fodder could mislead the results, where moisture content for fodder grown under a hydroponic system was very high compared to fodder grown under the conventional system.

Table 3. Yield, costs, and returns of barley green fodder under hydroponic and conventional cultivations.

Method	Hydroponic	Conventional
Dry matter yield kg m^{-2}	41.8	5.6
fixed m^{-2}	4 USD	0.45 USD
Variable cost m^{-2}	4.67 USD	0.48 USD
VC + FC m^{-2}	8.67 USD	0.93 USD
Dry matter yield kg m^{-2}	41.8	5.6
Dry fodder price kg^{-1}	0.2 USD	0.2 USD
Return (Dry) m^{-2}	8.3 USD	1.11 USD
Net profit (loss) m^{-2}	−0.31 USD	0.19 USD
Fixed cost kg^{-1}	0.1 USD	0.08 USD
Variable cost-kg^{-1}	0.11 USD	0.08 USD
FC + VC kg^{-1}	0.21 USD	0.16 USD
Profit (loss) kg^{-1}	−0.01 USD	0.13 USD

Source: Author's computations based on Supplementary Tables S1–S4.

Table 4 depicts results related to the benefit-cost analysis, the benefit-cost ratio for the hydroponic system is less than 1, indicating total costs (fixed and variable costs) exceed the total returns. In contrast, the benefit-cost ratio for the conventional system is greater than one confirming financial viability indicating, in economic terms, the superiority of the conventional system over the hydroponic system.

Table 4. Benefit-cost ratio for barley fodder production under hydroponic greenhouse and open field systems.

Method	Return/m^2	VC + FC	Benefit-Cost Ratio
Hydroponic	8.32 USD	8.67 USD	0.96
Conventional	1.11 USD	0.93 USD	1.2

Source: Author's computations based on Supplementary Tables S1–S4

Table 5 showed returns over variable cost and returns over total cost for the two cultivation methods applying the adjusted hydroponic greenhouse production budget from [24]. It is evident that the conventional method is profitable where positive signs for profits are estimated. However, the hydroponic method was at a disadvantageous position compared to the conventional method showing negative signs for profits (loss), confirming the above results.

Table 5. Returns on investment and over variable cost for barley fodder production under hydroponic greenhouse and open field systems.

Method	Hydroponic	Traditional Open Field
Fixed m^{-2}	3.95 USD	0.45 USD
Variable m^{-2}	4.67 USD	0.46 USD
VC + FC	8.6 USD	0.93 USD
Return m^{-2}	8.32 USD	1.11 USD
Returns/m^2 over variable cost	3.6 USD	0.64 USD
Returns/m^2 on investment	−0.31 USD	0.19 USD

Source: Author's computations based on Supplementary Tables S1–S4.

From Table 6, the break-even prices to cover variable and total costs per kg for the hydroponic method exceeded the break-even prices for the conventional method. The results are attributable to higher variable and total costs of producing fodder under the hydroponic system resulting in comparatively higher variable and total costs per kg. It may be noted that at the break-even price that covers the total cost, the profit is zero; profits are generated when prices are above the break-even price [22]. The break-even prices for the hydroponic and conventional systems were also estimated at 0.21 USD and 0.16 USD per kg, respectively. The market price of 0.20 USD, which is below the break-even price of the fodder produced under the hydroponic system by 0.01 USD indicating a loss, and above the break-even price of the fodder produced under a conventional system by 0.03 USD, indicating profit. The above results are consistent with the results in Table 3, assuring the economic viability of the conventional system in comparison to the hydroponic system. The break-even level of yield per square meter, which was estimated, based on the break-even volume of production that covers the fixed cost, exceeded the actual yield by 3.2 kg for fodder produced under the hydroponic system. Nevertheless, the actual yield of fodder produced under the conventional system exceeded the break-even yield by 1.57.

Table 6. Break-even prices and levels of fodder production under hydroponic greenhouse and open field systems.

Method	Break-Even Prices/Production and Yield	Value
Hydroponic	Break-even price to cover variable cost	0.11 USD
	Break-even price to cover the total cost	0.21 USD
Conventional	Break-even price to cover the variable cost	0.1 USD
	Break-even price to cover the total cost	0.16 USD
Hydroponic	Break-even volume for the period (77 days)	8593.939 kg
	Actual volume for the period	7982.128 kg
	Break-even yield/m^2 (area 190.96 m^2)	45 kg
	Actual dry matter yield/m^2	41.8
Conventional	Break-even volume for the period (77 days)	436.19 kg
	Actual volume for the period	604.8
	Break-even yield/m^2 (area 108 m^2)	4.03
	Actual dry matter yield	5.6

Source: Author's computations based on Supplementary Tables S1–S4.

Our results corroborated with Singh et al. [28], where economic valuation verified that the application of soilless culture as an alternative to conventional cultivation was not beneficial due to high principal investment. Our results are supported by Kaouche-Adjlanea et al. [16], where the economic assessment indicated the unprofitability of the hydroponic cultivation technique showing the superiority of the conventional open field to hydroponic cultivation methods. However, Ref. [17] it obtained opposite results, where hydroponic cultivation for off-season production of tomato and cucumber proved economic viability. Economic viability of feeding hydroponically cultivated barley fodder and maize to goats was proved in a previous study revealing relation to benefit-cost ratio [5].

Water is a vital element for the growing practices of fresh barley green fodder and dry matter yield whether produced in a hydroponic system or an open field. Based on 100% of ET_0 irrigation regime to produce 1 kg of fresh barley green fodder under conventional farming was 571.4 L, while 628.9 L are required to produce1 kg of dry matter. These results corroborated with [29]. On the other hand, the water requirement to produce 1 kg of fresh barley green fodder under the hydroponic technique, based on a 7-day harvest interval, was 6.9 L, compared to 37.2 L required to produce one kg of dry matter.

As a result of this study, the production of one ton of fresh barley green fodder produced under the hydroponic cultivation method required 2.83 m^3 of the quantity of irrigation water compared to 117 m^3 for barley fodder grown in the open field. For fodder grown under the hydroponic method of cultivation, WUE based on fresh green fodder and dry matter weight, declined with increasing the harvesting date. Under the hydroponic system, the highest WUE achieved based on fresh fodder weight was 411.1 kg m^{-3} while the lowest was 4.5 kg m^{-3} based on dry matter weight. However, for the open field, the WUE increased by reducing the irrigation regime. In the open field, the greatest WUE was 8.49 kg m^{-3} based on fresh fodder with 80% of ET_0 irrigation regime, while the smallest was 1.9 kg m^{-3} on the basis of dry matter weight with 100% of ET_0 irrigation regime.

These results revealed that the hydroponic barley fodder production required much less quantity of irrigation water to produce the same amount of fresh or dry matter green fodder compared to open field. Therefore, the hydroponic cultivation technology for green fodder production is highly efficient in conserving homogenous amount of irrigation water compared to open fields. Despite water conservation advantages of the hydroponic cultivation system, results proved that the system is economically unviable for small-scale farming, attributable to high fixed and variable costs.

4. Conclusions and Recommendations

Water conserving technology research is vital for sustaining the animal sector and saving the crucial limited water resources in Saudi Arabia. This study focused in assessing water conservation and economics of barely green fodder production under the hydroponic and the open field systems. Regarding water conservation analysis, water use efficiency of the barely green fodder production under the hydronic system was much higher than the open field. Moreover, hydroponically, based on the fresh fodder and dry matter weights, the WUE decreased with increasing the harvesting date. The highest WUE of 411.1 kg m^{-3}, based on fresh fodder weight, obtained under the hydroponic along with the lowest of 4.5 kg m^{-3}, based on the dry matter weight. The one square meter of the hydroponic technique produced fresh green fodder 2.83 times higher than the open field and 2.3 times for the dry matter yield. Therefore, to produce one tone of barely green fodder hydroponically required 2.83 m^3 compared to 117 m^3 by the open field. In comparison, the water use efficiency of the barley green fodder, based on the fresh matter, under the hydroponic cultivation was 48 times greater than the conventional. However, based on the dry matter, under the hydroponic cultivation it was three times greater than the conventional. In summary, the hydroponic system is a useful technique for water conservation in the KSA, and proved superior over the conventional cultivation system.

Economic wise, the profitability was maintained only for the conventional cultivation method amounting to 0.19 USD per square meter and a benefit-cost ratio equal to 1.2. In contrast, a loss of 0.31 USD per square meter and a benefit-cost ratio equal to 0.96 in the case of the hydroponic method was induced by high variable and fixed cost.

One of the drawbacks during this study was that the produced hydroponic fresh barely green fodder sometimes was infected with mold. This mold caused the fodder to be implantable to the animals under trials and negatively affected their weights.

Based on the outcomes of the economic analysis, more investigations are needed before shifting from the traditional to the hydroponic method for barely green fodder production. Moreover, further research is required for hydroponic green fodder production units with a highly controlled environment and intensive sanitation and hygiene.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su15010822/s1. Table S1. 1-Fixed cost for hydroponic system for fodder production. Table S2. 2-Variable cost for hydroponic system for fodder production. Table S3. 3-Fixed cost for traditional open field system. Table S4. 4-Variable cost for traditional open field.

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