ENGINEERING FACTORS AFFECTING HYDROPONICS GRASS- FODDER PRODUCTION

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ABSTRACT

Animal production and its industrial investment is overwhelmed with various problems due to the insufficient animal feeding requirements and the competition with the human crop requirements. Therefore, about third of the total cultivated area of the world is covered with the animal feeding crops. In this regard, efforts have to be carried out to develop new techniques to face this competition. The aims of this study are to: 1) establish a hydroponic unit for intensive grass fodder production; 2) study the engineering parameters affecting the efficiency of the suggested unit such as light intensity and duration of aeration, nutrient solution and its characteristics and applied amounts of water, and 3) determine the total energy requirements for improving the unit production capacity.

Therefore, a closed hydroponic system was established at the Central Lab.of Agric. Eng. Agric. Eng. Dept., Faculty of Agric., Ain Shams Univ., to achieve the abovementioned objectives. However, experimental layout included lighting system to provide plants with its lighting requirement, cooling and air conditioning unit to conserve the appropriate micro-climate conditional to propagate a healthy plants and equipment, aeration and CO_2 proportioning system, to enhance the root-zone media with its air balance and requirements to avoid the plant stress.

Treatments of the affecting parameters could be summarized as follows:

a- Engineering factors: 1) lighting time (8, 12, 16, and 24 h/day) with a fixed intensity of about 2021 lux, 2) aeration (36, 60, and 84 min/day), and 3) irrigation period (1, 2, and 3min/2h).

Results of the hydroponics barley-grass fodder production under different treatments could be summarized as following:

a_1- The optimum lighting operating hours (2000 lux in intensity)for barley – fodder production under the suggested hydroponic system was about 12- 16

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hours is the most suitable for fodder production of barley, and the vegetative growth.

a_2- Aeration time had a significant effect on the barley–production under the suggested hydroponics. However, there was a positive proportional relationship with all studied parameters, indicators and the aeration flow rate in terms of operating time. So, the best aeration flow rate was 3min/2h per day.

b- Energy requirement: the total energy consumption for barley production under closed hydroponics systems was about 138 W/h.

INTRODUCTION

NFT is a true hydroponics system where the plant roots are directly exposed to nutrient solution. A thin film (0.5 mm) of nutrient solution flows through channels **(FAO, 2004).**

Hydroponic fodder is essentially the germination of a seed (such as malt barley or oats) and sprouted into a high quality, highly nutritious, disease free animal food. This process takes place in a very versatile and intensive hydroponic growing unit, where only water and nutrients are used to produce a grass and root combination that is very high in nutrients. This green fodder is extremely high in protein and metabolic energy, which is highly digestible by most animals **(Cader, 2002).**

Light is not required to sprout cereal grains. Some light in the second half of the sprouting period encourages photosynthesis and greening of the sprouts.If the seedlings are grown without light or too low a light intensity, photosynthesis is non-existent or minimal **(Peer and Leeson 1985)** and seedlings must rely on their starch and fat reserves to meet their energy demand. Where sprouts are stacked inside a shed many, sprouts may be heavily shaded.

Morgan et al. (1992) found little difference between treatments in DM content when grass was provided with 1000 lux from day 2, 4, 6 or 8. Grass supplied with light from day 8 appeared unattractively yellow whilst the highest light level caused a decrease in grass height, probably due to reduced etiolation1. Two days illumination was required to green the grass.

O'Sullivan (1982), reported increased losses of DM, where no light was provided. He found that the rate of decrease of DM content slowed down after day 4 in lighted experiments, when leaves began photosynthesising. In agreement with **Morgan et al. (1992),** lighting prior to day 3 was of little significance.

MATERIALS AND METHODS

1. Experimental layout:- Experimental layouts and procedure had been described in Fig. (1). However, the experimental layout included lighting system to provide the grown plant with its lighting requirement, cooling and air conditioning unit to conserve the appropriate micro-climate condition to propagate a healthy plant and equipment, aeration and CO_2 proportioning system, to enhance the root-zone media with its air balance and requirements to avoid the plant stress.

2. Fodder-hydroponic system:- The hydroponic system (Fig. 2) consisted of the following parts: frame, growth trays and aeration, lighting, cooling, irrigation, supernatant collection and control units.

2.1 Frame:- The frame was constructed of aluminum angles with a length of 125 cm, a width of 36 cm and a height of 48 cm. The prototype were covered with 0.4 cm thick plastic sheets. The frame supported the growth trays and all other systems.

2.2 Plant growth unit:- The plant growth unit consisted of trays. Each tray was made of foam with dimensions of 30 x 30 x 4 cm. The bottom of trays was perforated with 1.5 mm-diameter holes diameter and spacing of 20 mm. The plant supporting trays were positioned in the troughs so that the plant roots were in contact with the liquid. The placement of trays was maintained by means of supports with dimensions of 2.5 x 2.5 x 2.5 cm and stuck below the corners of each tray.

2.3 Aeration unit:-An aeration unit was installed to provide oxygen to the system for plant growth. The aeration unit consists of cooling fan 1200 rpm with 17 cm vane diameter connected with controller sensing. The fan was fixed on the top of frame with 4 bolts.

2.4 Lighting unit:- The lighting unit was designed to provide approximately 2000 lux meter of illumination per tray. This was achieved by 2 white fluorescent lamps (120 cm in length) with 40 W. The lamps were fastened above each tray and controlled in operating time by controller timer of capacity 24h, with accuracy of 5min.

2.5 Cooling unit:-A cooling unit was designed to continuously remove the heat produced by the lamps to avoid heating of the recycled water.

The cooling unit consisted of water tank with 3 liter size, and shaft with clothes sheet which rotates into the tank and fan with 17 cm diameter. The fan air flows through the clothes sheet. The cooled air flow on the top of growing plants. The fan was attached vertically to the right side of the frame, through which air was blown by means of a motor driven fan of 30 Watt.

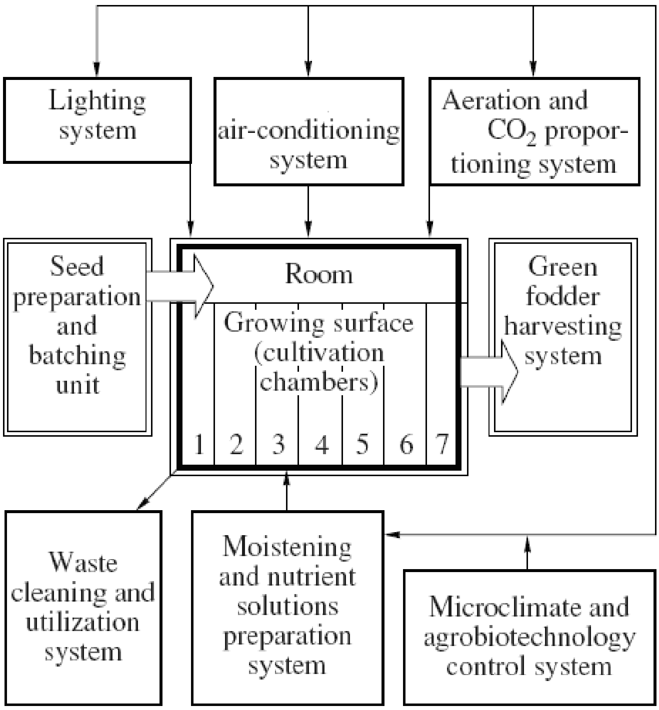
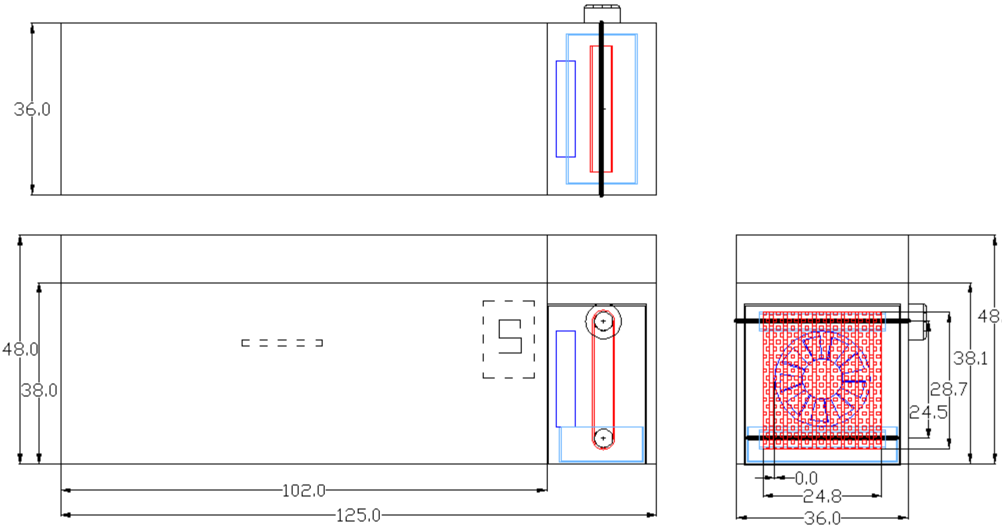


Fig (1) : Flowchart of fodder-hydroponic system.

2.6 Supplementary irrigation unit: - The recycled water application unit consisted of the following parts:

- A water storage tank with 12 liter size, for storing the water and nutrient solution.
- A 32 Watt- submersible pump in storage tank of discharge 2000 lph with 0.2 bar, to transfer the water from the storage tank to the irrigation system. The pump was connected to the irrigation system using P. E. tubing of 16 mm outside diameter.
- A valve, to control the amount of water fed to 4 mini-sprinklers and, for applying the water into the plant supporting trays. The timing and

duration of opening/closing of the valve was controlled by an electronic circuit.



Dim. In cm

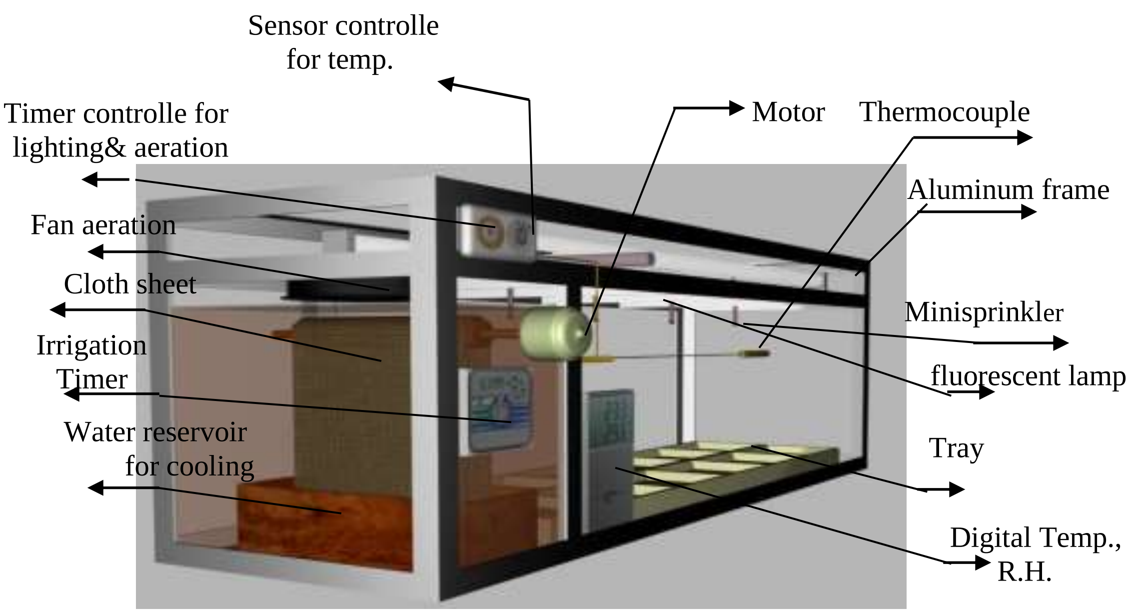


Fig. (2): Prototype fodder hydroponics system.

- Irrigation control: EC model 200i/201i – 2-stations indoor controller with the following features: 3 programs: A, B, C, start times: 4 per day, per program, for up to 12 daily starts, station run time: 0 minutes to 4 hours in 1-minute increments, day schedule: 7-day calendar or interval (1-31 day) watering, transformer input: 110VAC, 60 Hz, transformer output: 24VAC, 0.625A.

- Mini sprinkler of discharge was 10.2 lph at 1.8 m head , with covered radius 35 cm.

2.7 Drainage unit:-The drainage unit consists of collecting bin stuck under the plant trays. The water exit out the bin to storage tank by P. E. tube with diameter of 4 mm.

3. Micro – climate and agro-biotechnology control unit

- **Temperature thermocouple**: consists of gauge capacity 40ºC, with an accuracy of about 2ºC and sensor electrode to measure the temperature inside growth room .
- **CO_2 injection**: consists of feeding bottle from $CaCO_3$ and bottle from HCL to produce CO_2 through 4mm pipe diameter inside growth room .
- **Nutrient solution**: Inorganic nutrient solution (control), **(El-Behairy, 1994)**

Elements	Concentration (ppm)	Elements	Concentration (ppm)
N	259.6	Fe	5
P	35	Mn	1
K	300	B	0.3
Ca	160.2	Cu	0.1
Mg	50	Mo	0.1
S	221	Zn	0.1

The electrical conductivity (EC) of the nutrient solution was maintained between 0.31-0.33 mmhos cm^{-1} and the pH was maintained at 7.0-7.2 using citric acid for all-organic solutions. On the other hand, the nutrient solution volume was adjusted once a day by adding tap water up to recognized mark in the tank. The amount of water was measured and recorded for calculation of water consumptive use. The nutrient solutions were completely renewed every day.

4. Experimental procedure and treatments:-To evaluate the grass-fodder production under hydroponic system, the following technical parameters and their associated treatments had been considered.

4.1 Lighting time:-The indoor lighting operating hours in the hydroponic system to conserve the fodder crop lighting requirements had been investigated. However, the lighting operating hours under the same lighting intensity were 8, 12, 16, 24 hours/day. However, the lighting intensity was 2000 lux.

4.2 Aeration rate: - Different aeration rates of 2, 3, 5 min/2h had been evaluated**.**

4.3 Water consumptive use:- Tap water was added to each compartment as required to compensate for water losses due to evaporation. However, the barley water requirement had been calculated based on average of 5-6 mm/day (according to ET_0 from **FAO, 2004**). Therefore, the operating time of the supplemental irrigation system had been calculated according to the following formula:

Operating time (min/day) = Evapotranspiration (mm/day)/perception rate (mm/min.)

4.4 Water use efficiency:- Water use efficiency (WUE) is an indicator of efficiency of irrigation unit for increasing crop yield. WUE was calculated, according to **Jensen (1983)** as follows:

$$WUE\ (g/L) = \frac{Barley\ yield\ (g/m^2)}{Amount\ of\ \ applied\ irrigation\ water(L/m^2)} ------(1)$$

5. Crop yield components, productivity and attributed quality

5.1 Plant materials:- Barley seeds (Giza, 124), were used in this study. The seeds were soaked for 24 hours and transplanted on prototype.

5.2 Plant measurements:-For every day time, from transplanting the following measurements of vegetative growth were recorded. Measurements included growth indicator parameters. However, the indicated parameters and attributed indices can be categorized as follows:

5.2.1 Vegetative growth parameters: Plant growth height and plant root length**.**

5.2.2 Yield productivity parameters :-Fresh, dry vegetative growth and root yield (g/cm^2).

5.3- Yield quality:-Moisture content %, dry matter %, protein %

*** M.C. % =100 (Fresh yield weight – Dry weight)/ Fresh yield weight -(2)**

**** D.M. %= 100 (Dry weight / Fresh yield weight) ---------- (3)**

***** Portien % = N % * 5.5 -------------------------------------- (4)**

Where : *M.C%: moisture content percent , **D.M.%: dry matter percent and * portien % : portien percent.**

2.6 Cost analysis

Cost of operation was calculated according to the equation given by **Awady (1978),** in the following form:

$$C = p/h\ (1/a + i + t/2 + r) + (Ec * Ep) + m/144, \text{-------------}(5)$$

Where: C = hourly cost L.E/h, p = price of prototype (L.E.), h = yearly working hours, a = life expectancy of the machine (year), i = interest rate/year, t = taxes, r = overheads and indirect cost ratio , , Ec = electricity consumption kW.h/h, Ep = electricity price L.E/kW.h, "144" is estimated monthly working hours. Notice that all units have to be consistent to result in L.E/h.

RESULTS AND DISCUSSION

Data presented in Figs. (3,4,5,6,7) revealed that fodder production and attributed quality parameters are significantly influenced with all engineering factors such as lighting hours, aeration and irrigation period .

1- Lighting

The effect of lighting operating hours (2000 lux in intensity) on the barley –fodder production under the suggested hydroponic system had been evaluated. Results revealed that, in general terms, the lighting operating hours of about 12-16 hours is the most suitable for fodder production of barley. However, the highest values of the studied indicators were obtained at this range. The discussion of this parameter was based on the constant values of 8 days growing, 3min /2hours, aeration and injection of CO_2, and 184.8 g/cultivation unit area ($0.09m^2$).

a-Vegetative growth parameters

Results presented in Fig.(3) indicated that root length dose not influence with lighting operating hours, however its values was about 6 cm under all treatments of lighting (8,12,16, and 24 hours/day). On the other hand ,data speculated that vegetative length of barley had been significantly affected with lighting operating hours. However, the increasing of the vegetative length was about 5.88, 0 and 16.67 % with application of 8-12, 12-16 and 16-24 lighting time (hours/day). The above mentioned results are in agreement with those observed by **Morgen et al. (1992).**

b-Yield and W U E

Data illustrated in Fig. (4) indicate that barley yield had the same trend of the vegetative growth. However, increasing rate of yield with about 109.73 gm with increasing the lighting operating hours from 8 up to 12 hours/day, after then, it had decreased with a little value of about 6.96 % with increasing the lighting

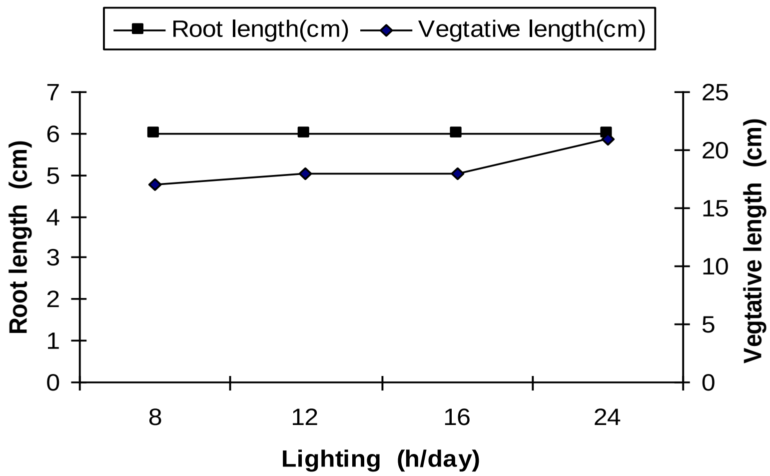


Fig 3. Effect of lighting operation hours on vegetative growth

hours from 12 up to 16 hours/day, and the yield reduction percentage was about 35.13 % when increasing the lighting hours from 16 h up to 24 h/day. This means that the most suitable lighting hours ranged from 12 up to 16 h/day for barley fodder production under closed hydroponics system. This may be due to that after the 16 h lighting, the highest light level caused a decrease in rate of grass height, due to diminishing efficiency of light use. Data are in agreement with **(O' Sullivan, 1982).** Regarding the WUE, the same trend had been observed due to the constant application of water.

c-Attributed yield quality parameters

Data presented in Figs (5, 6, 7) revealed that the lighting hours of about 12-16 hour/day is the most suitable for barley-production under hydroponics system and also to observe the high level of quality of the obtained yield.

However, the same trend had been observed for percent of protein, moisture content of the final production and the total dry matter of vegetative yield or root yield. However, data suggests that photosynthesis not important for the metabolism of seedling until the end of 12 h lightly, when the chloroplasts are activated. These findings are in agreement with those observed by **(Trubey et al., 1969).**

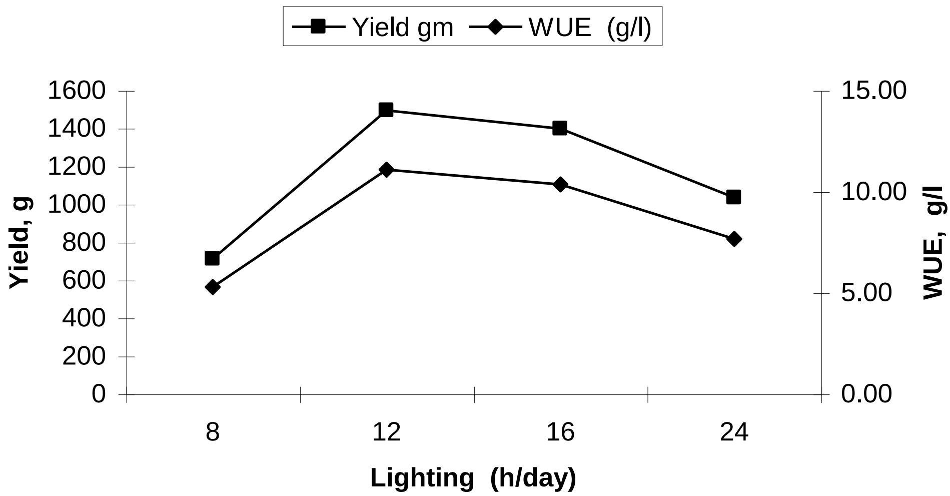


Fig (4) : Effect of operating lighting hours on total yield and WUE.

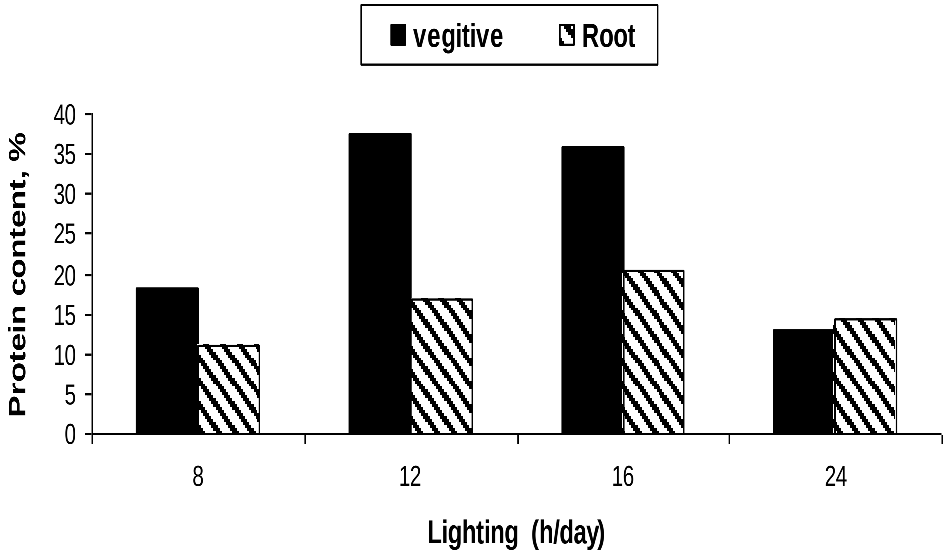


Fig (5) : Effect of operating lighting hours on crude protein.

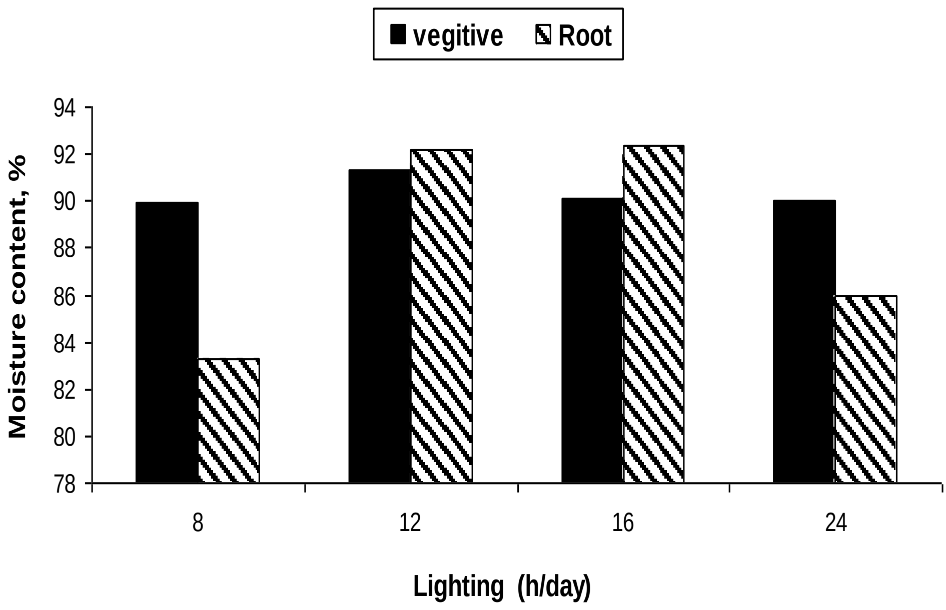


Fig (6) : Effect of operating lighting hours on moisture content.

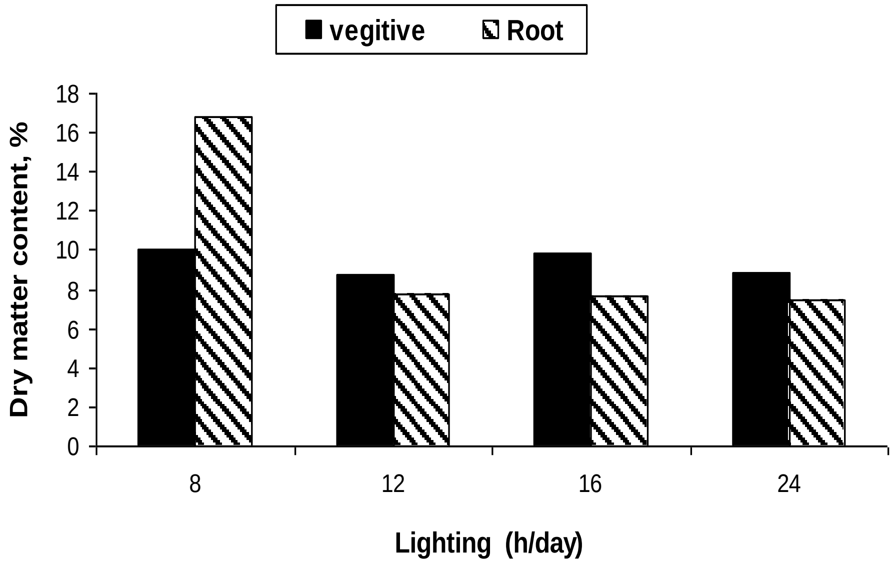


Fig (7) : Effect of operating lighting hours on dry matter.

2- Aeration

Aeration time had a significant effect on the barley –fodder production under the suggested hydroponics. However, there is a positive proportional relationship with all studied parameters and indicators, and the aeration flow rate in terms of operating time. The discussion of this parameter was based on the constant values of 8 days growing, 12h/day lighting, injection of CO_2, and 184.8 g/ 0.09m$^{2.}$

a- Vegetative growth parameters

Results presented in Fig. (8) indicated that all studied vegetation growth indicators (vegetative and root length) were not significantly affected with the treatments of aeration. The above- mentioned results are in agreement with those observed by **Morgen et al. (1992).**

a- Yield and WUE: data indicated that barley yield had an inverse relationship with the aeration flow rate. However, a reduction in either barely yield or WUE had been observed with increasing the air flow rate in terms of aeration time, as shown in Fig. (9). These findings are in agreement with those indicated by **Morgen et al. (1992).**

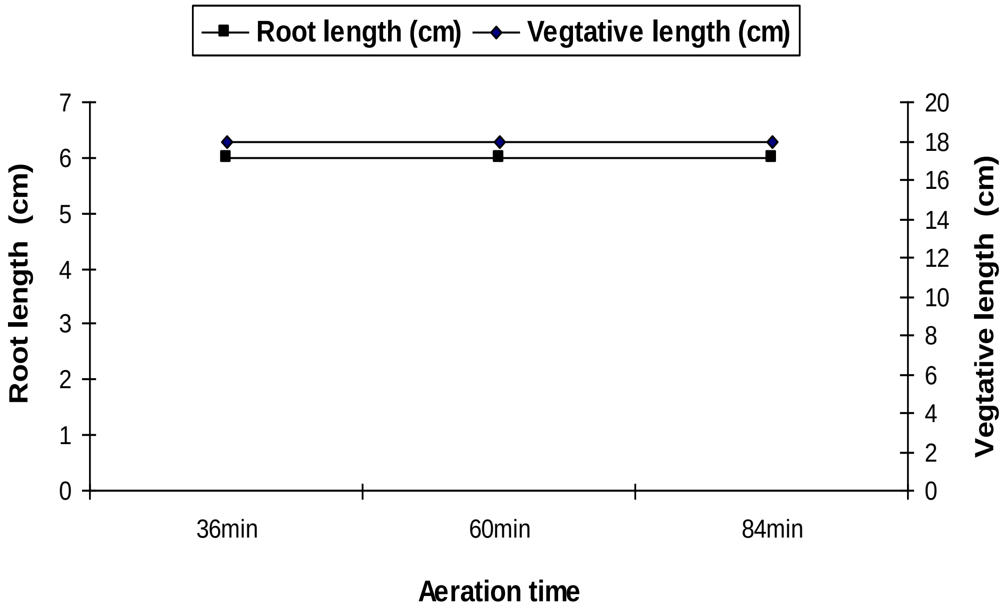


Fig (8): Effect of aeration rate on vegetative growth.

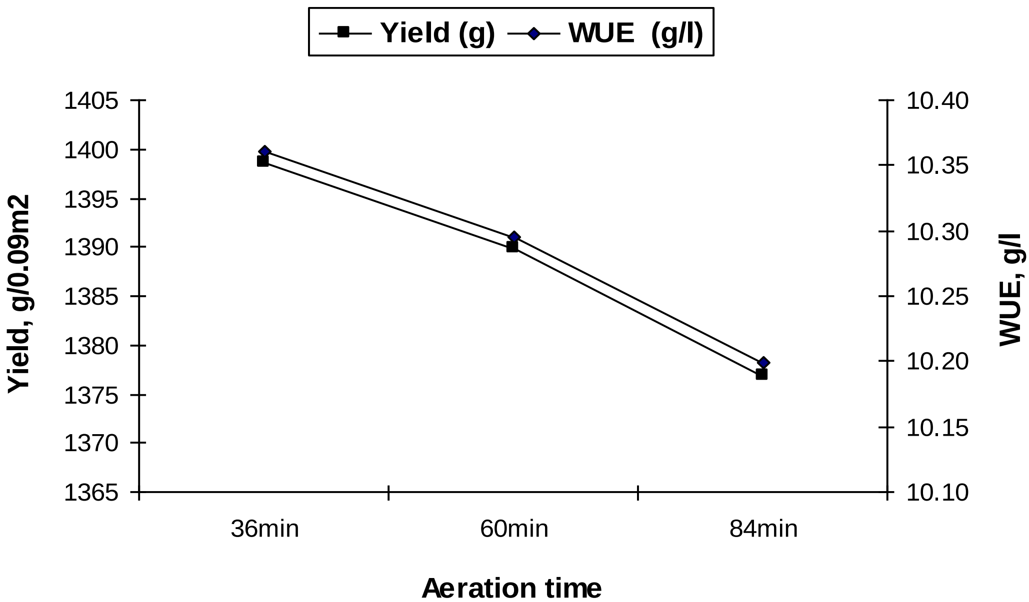


Fig (9): Effect of aeration rate on yield and WUE.

c- Attributed yield quality parameters:

Barely yield quality response to the applied aeration rate had been investigated. There was no effect on the protein percent. On the other hand, aeration had a significant effect on the total dry matter of the barely yield, as presented in Figs. (10, 11 and 12).

3- Supplementary irrigation period

The principal secret to successful barely grass production under hydroponics lies in the provision of optimum irrigation. However, improved irrigation appeared to offset the effect of temperature on the barely crop.

a- Vegetative growth parameters

Results indicated that the irrigation period had a non homogeneous effect on the vegetative length, and had no effect on the root length.

b- Yield and W. U. E.

Data indicated that barley yield had an inverse relationship with the aeration flow rate. However, a reduction in either barely yield or WUE had been observed with increasing the air flow rate in terms of aeration time, as by **Morgen et al. (1992).**

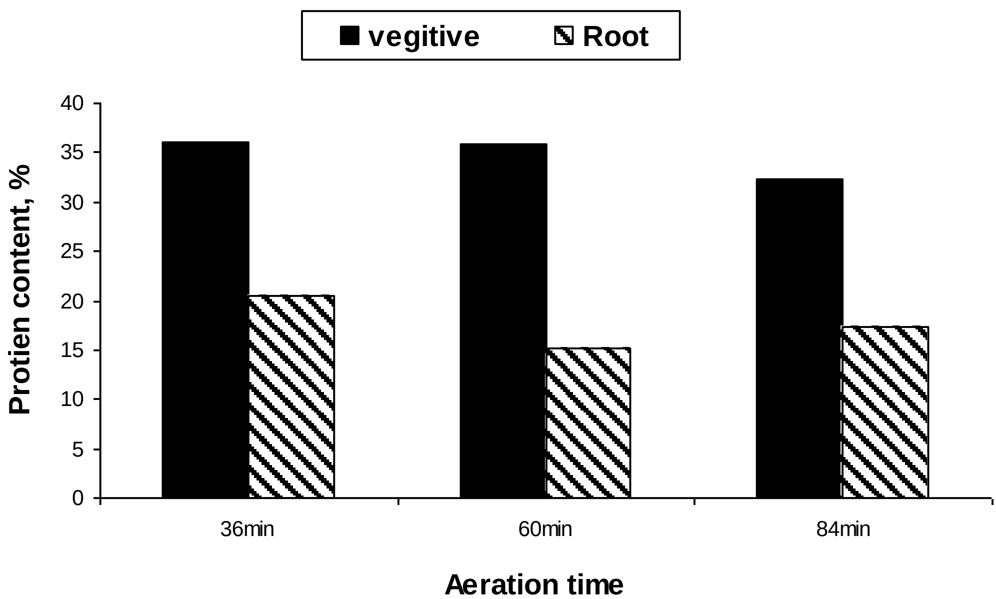


Fig (10): Effect of aeration rate on Protien content.

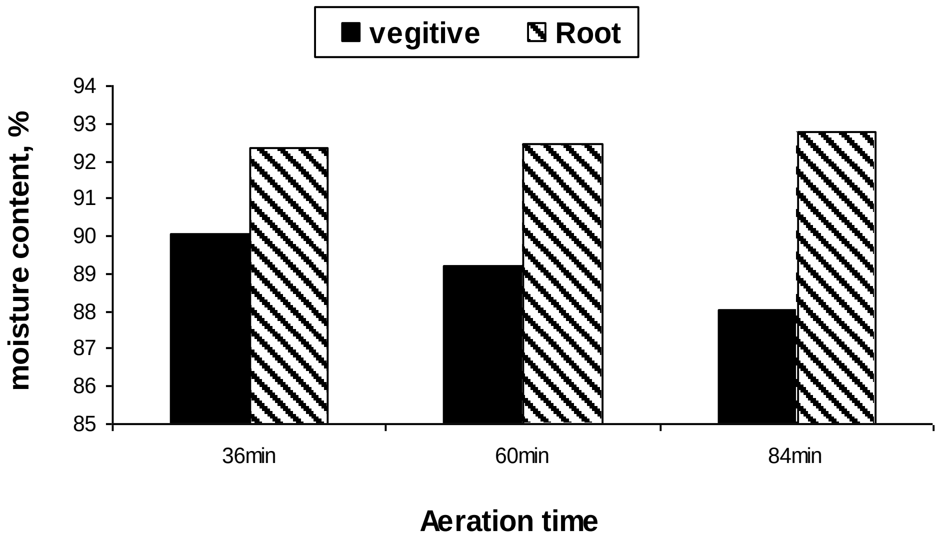


Fig (11): Effect of aeration rate on moisture content.

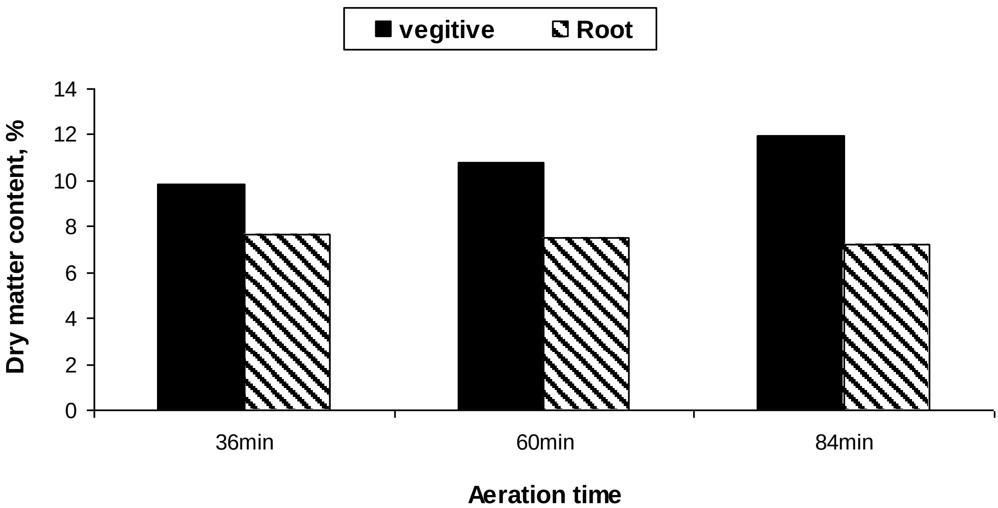


Fig (12): Effect of aeration rate on dry matter.

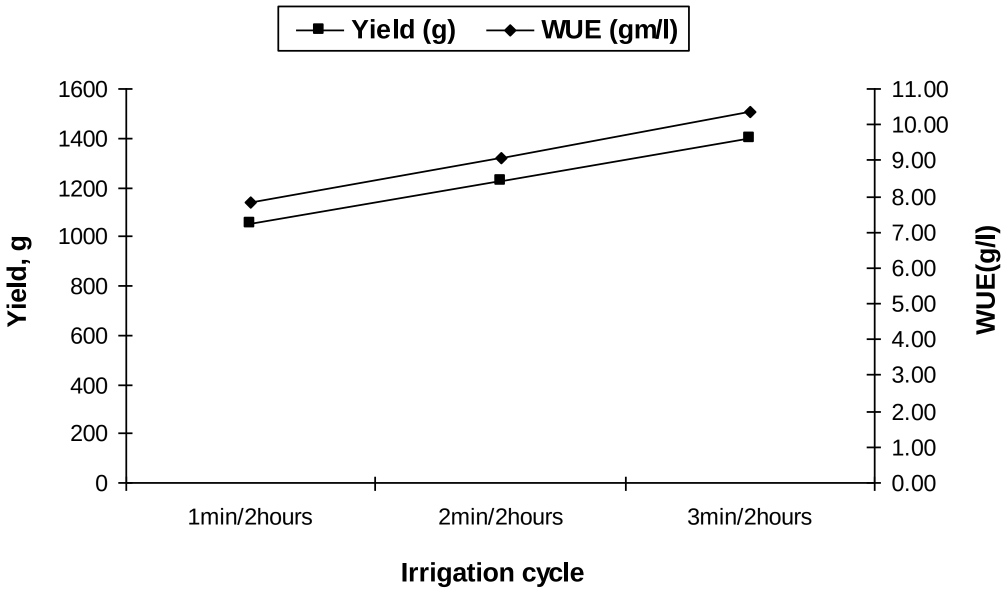
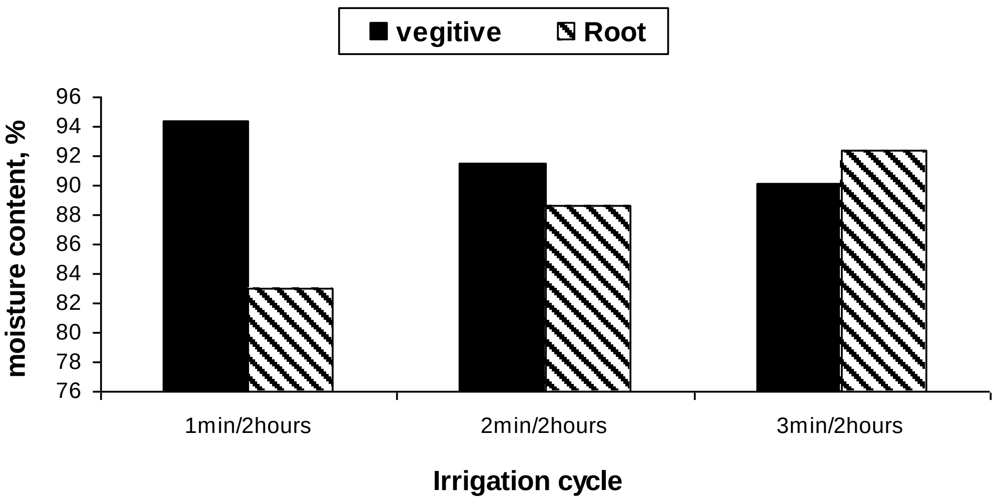


Fig (13): Effect of irrigation cycle on yield and WUE.

c- Attributed yield quality parameters

Barely yield quality response to the applied aeration rate had been investigated. However, there was no effect on the protein percent. On the other hand, aeration had a significant effect on the total dry matter of the barely yield, as presented in Figs. (14, 15, and 16).



Fig(14): Effect of irrigation cycle on moisture content.

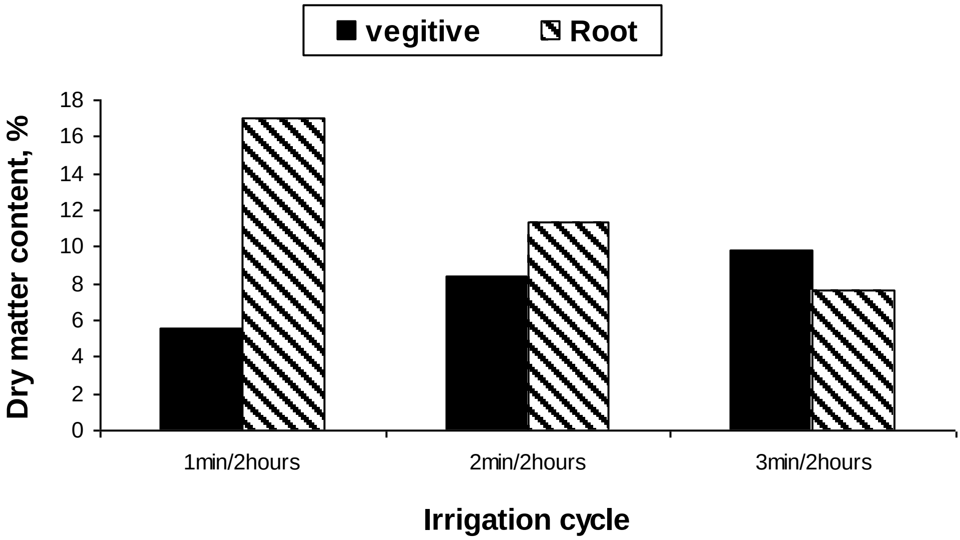


Fig (15): Effect of irrigation cycle on dry matter

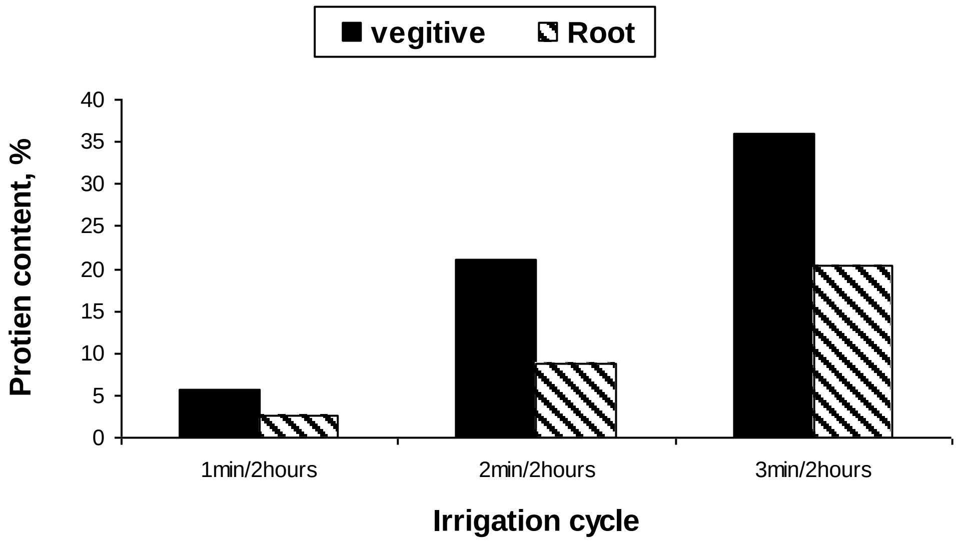
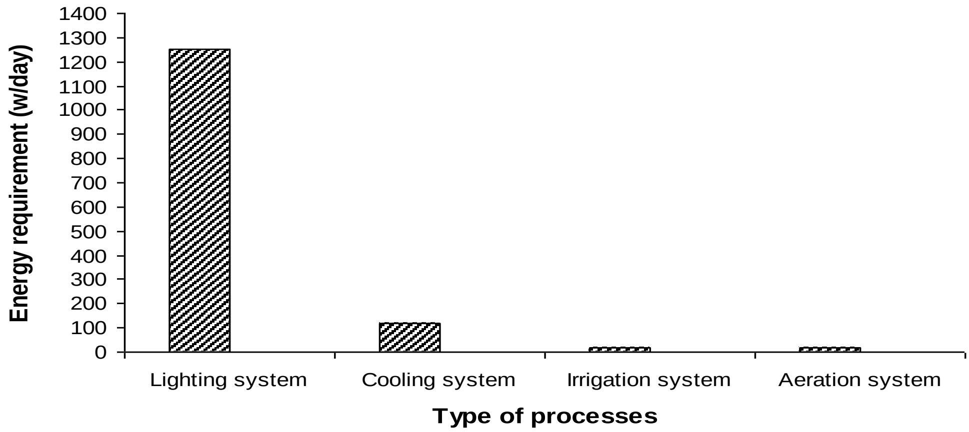


Fig (16): Effect of irrigation cycle on protein.

4- Energy consumption of hydroponics fodder production

The total energy consumption for barley production, under closed and controlled hydroponics systems, was about 138 w/h. However, the highest energy consumptive value was 78 w/h for lighting process, and the lowest value was0 .6 w/h for irrigation process, as presented in fig. (17).

With respect to the total energy requirement for a 8 day producing cycle of barley-grass fodder, data revealed that the estimated energy may be about 11.2kw/8day.



Fig(17): Energy requirement for differenet processes

5- Cost analysis: The total cost for barley production under closed and controlled hydroponics systems was about 4L.E/day. However, to produce 10.39 kg/day fresh green in area 1m^2, and one kilogram from fresh green will cost 1L.E. so the net profit will be 6.39 L.E/day, as by **Morgen et al. (1992).**

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الملخص العربي

تأثير العوامل الهندسية على وحدة إنتاج اعلاف خضراء بالزراعة المائية

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تعتبر تنمية الانتاج الحيوانى أحد الأهداف الهامة للاسترتتيجيات الزراعية، ونتيجة لهذا فان حوالى ٣/١ المساحة المنزرعة على مستوى العالم تستخدم لتوفير الاعلاف الخضراء. ومع نقص الموارد المائية وزيادة الحاجة الى التوسع الزراعى لمجابهه الزيادة السكانية ، فإن ذلك يدعونا الى توجيه تلك المساحة الى زراعة أخرى مع تطوير طرق الزراعة بما يلائم الظروف المحلية ، كزراعة بعض محاصيل الأعلاف الخضراء على مدار السنة، وفى غير مواسمها الطبيعية . وتطبيق الزراعة المائية هى احدى التكنولوجيات الحديثة التى يجب الاهتمام بها فى هذا المجال لتوفير الاعلاف على مدار العام ، حيث تمتاز بالقدرة العالية على التحكم الكامل فى بيئة الجذور والحصول على منتج خالى من أى تلوث . ومن أهم أهداف هذه الدراسة :

١) انشاء وحدة لانتاج الأعلاف الخضراء على مدار العام.

٢) دراسة المعايير الهندسية وكفاءتها مثل مدة الاضاءة ، واضافة المحاليل المغذية وكميات المياه المضافة.

٣) تحديد إحتياجات الطاقة المطلوبة لتطوير وحدة انتاج الاعلاف الخضراء.

لذلك تم انشاء وحدة أعلاف خضراء فى المعمل المركزى بقسم الهندسة الزراعية-كلية الزراعة- جامعة عين شمس ، حيث يتضمن تخطيط التجارب عددا من المعايير مثل نظام الاضاءة لاعطاء النباتات إحتياجاتها من الضوء، نظام تبريد تبخيرى للمحافظة على درجات الحرارة داخل النموذج فى حدود المسموح بها للانبات ، نظام تهوية وإضافة $CO_٢$ لتحسين وسط النمو وعمل اتزان لبيئة الجذور وعدم حدوث إجهاد للنباتات .

والمعاملات الهندسية التى تم اجرؤها يمكن تلخيصها فيما يلى :

١- فترات الاضاءة (٨، ١٢، ١٦، ٢٤ ساعة/يوم) مع ثبات شدة الاضاءة عند ٢٠٠٠ لكس.

٢- فترات التهوية (٣٦ ، ٦٠ ، ٨٤ دقيقة / يوم) .

٣- فترات الرى (١، ٢ ، ٣ دقيقة / ٢ ساعة).

ونم أخذ قياسات على النباتات من أطوال للمجموع الخضرى ، والجذرى ، ونسبة البروتين ، والمحتوى الرطوبى ، ونسبة المادة الجافة فى العينات المأخوذة.

وكانت أهم النتائج كالتالى :

١- أفضل ساعات إضاءة عند ثبات شدة الاضاءة ٢٠٠٠ لكس للمحصول الشعير تحت نظام وحدة الاعلاف الخضراء بالزراعة المائية هى بين ١٢- ١٦ ساعة/يوم ، حيث أعطى أفضل انتاجية للمحصول.

٢- أفضل زمن للتهوية تحت نظام وحدة الاعلاف الخضراء بالزراعة المائية والتى أعطت أفضل انتاجية لمحصول الشعير هى ٣ دقائق/ ٢ ساعة فى اليوم.

٣- كانت متطلبات الطاقة لوحدة الأعلاف الخضراء بالزراعة المائية هى ١,٤ كيلو وات / يوم .