Barley Cultivars and Seed Rates Effects on Energy and Water Productivity of Green Fodder Production under Hydroponic Condition

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ABSTRACT
Background: Green fodder availability for livestock is decreasing because of climate change impacts on crop productivity and scarcity of land and water resources. Therefore, barley green fodder production in hydroponic systems could be an alternative to ensure sustainable green forage production for livestock. In spite having advantages such as high nutritional and economical values, marginal land use, providing natural feed for animals, and availability during all seasons of year, green fodder production in hydroponic systems should be evaluated from energy, water productivity, and GHG emissions intensity point of view. Therefore, this study aimed to evaluate the effect of barley cultivars and seed rates on the energy indices, GHG emissions intensity, and water productivity of barley green fodder production under hydroponic condition.

Methods: This research was conducted in the form of a completely randomized experimental design with two factors, 12 treatments, and 12 replications. Barley cultivars of Raihan, Behrokh, EC and Fasih were main factors, and seed rates of 600, 700 and 800 g/tray were considered as subplots. Input and output energies, energy indices, fodder dry matter, water productivity and GHG emissions intensity were determined in this study.

Result: Results showed that barley cultivar and seed rate had significant effect on fodder dry matter, water productivity, and GHG emission intensity; while, energy indices were only affected by barley cultivars. Behrokh cultivar had the highest fodder dry matter, water productivity, energy indices and the lowest GHG emission intensity. Seed rate of 800 g/tray provided the highest fodder dry matter, water productivity and lowest GHG emission intensity. Therefore, Behrokh barley cultivar with seed rate of 800 g/tray was recommended for barley green fodder production in hydroponic systems in semi-arid climate condition of Iran.

Key words: Fodder dry matter, Energy indices, Energy share.

INTRODUCTION

Barley is an important feed crop in Iran which is planted as irrigated and rain-fed field crop. Since barley is a winter crop in Iran, energy use and GHG emissions are usually low and water productivity is high in field barley growing compared to summer feed crops. Energy requirements for irrigated and rain-fed barley production in Fars province, Iran are 25 and 13 GJ ha⁻¹, respectively and electricity generation and consumption has the highest impact on environment (Houshyar, 2017). Values of metabolizable energy and net energy for lactation in samples harvested at mature state of barley are lower than in those harvested at heading and seed formation stages (Guney et al., 2016). Input energy, output energy, energy use efficiency and energy productivity for barley production in Sistan and Baluchestan province of Iran are 25.7 GJ ha⁻¹, 49.8 GJ ha⁻¹, 1.49 and 0.066 kg MJ⁻¹, respectively (Ziaei et al., 2015). Input energy, output energy, energy use efficiency, energy productivity and net energy gain for barley production in Thrace region of Turkey are 16950 MJ ha⁻¹, 92234 MJ ha⁻¹, 5.44, 0.25 kg MJ⁻¹ and 75283.45 MJ ha⁻¹, respectively (Firat Baran and Gokdogan, 2014).

Green fodder availability for livestock is decreasing because of climate change impacts on crop productivity and scarcity of land and water resources. Therefore, green fodder production in controlled conditions could be an alternative to ensure sustainable green forage production. Advantages of hydroponic production system are high nutritional and economic values, marginal land use, low labour requirement, providing natural feed for animals, high water productivity and availability during all seasons of year (Bekuma, 2019). Around 8.22 kg green fodder is produced from one kg barley seed after 7 days of sprouting in hydroponic condition (Ansari et al., 2019). Results of comparing barley cultivars in hydroponic condition in Jordan indicates that local variety...
has the higher green and dry fodder yields and water productivity compared to ACSAD176 and Rum cultivars (Al-Karaki and Al-Momani, 2011). Dry matter yield, fodder quality and water use efficiency of barley fodder in hydroponic condition is significantly affected by barley cultivars (Emam, 2016). Barley seed rate has also significant effect on barley fresh and dry fodder yields so that fresh and dry fodder yields increase with increasing seed rate (El-Morsy et al., 2013). Water use efficiency of barley green fodder is higher than that of cowpea, sorghum, wheat and alfalfa in hydroponic conditions (Ghazi et al., 2012). Using organic nutrient solution in oat and ryegrass green forage production in hydroponic condition results in higher quantity and quality forage compare to use of conventional (synthetic) nutrient solutions (Riveroa et al., 2016). Objective of this study was to evaluate the effect of barley cultivars and seed rates on the energy indices, GHG emissions intensity and water productivity of barley green fodder production under hydroponic condition.

MATERIALS AND METHODS
The research was conducted in the form of a completely randomized experimental design with two factors, 12 treatments and 12 replications at the Fars Research and Education Center for Agriculture and Natural Resources, Iran. Four local barley cultivars including Raihan, Behrokhi, EC and Fasli were selected as main factors and three seed rates including 600, 700 and 800 g/tray (3.33, 3.89 and 4.44 kg m⁻²) were considered as subplots. The research was conducted in the hydroponic production unit of Nobar Niriz Food Industry Company, Niriz (Southern Iran, 54°20’E, 29°12’N and 1595 m above sea level), Iran in 2017-2018. The hydroponic system was composed a cabinet with metal frame and dimensions of 700×1000 cm. The cabinet consisted of seven shelves and each shelf with 120 planting trays. Polyethylene trays with dimensions of 30×60 cm were used as seed bed. Air conditioning system was used to control temperature inside the growth room which was maintained at 18-20°C. The cleaned seeds were sterilized by soaking in a 2% sodium hypochlorite solution for 20 minutes to control moulds. Planting trays and the growing substrates were also cleaned and disinfected. The seeds were then washed well from residues of bleach and re-soaked in tap water for 8 hours before planting. Seeds were sown in the polyethylene trays with holes at the bottom to allow drainage of excess water from irrigation. The trays were stacked on the shelves of the hydroponic system and the mist irrigation system was used to irrigate the seeds for two minutes every two hours. After 10 days from seeding, the produced green fodder was ready to harvest; therefore, green plants with their root mats in the trays were harvested and green and dry fodder yields were obtained.

Input and output energies for barley green fodder production process were calculated and water productivity and energy indices were determined. Input energy sources were human labor, facilities, pumping water (water used for irrigation and washing trays, shelves and cabinet floor), seeds, sterilizing chemicals and electricity. Output energy source was barley fodder dry matter. Input energies were obtained by multiplying the amount of input used by the energy equivalent of that specific input (Table 1). Input energy related to the facilities used for barley green fodder production in this research was obtained using the equation suggested by Kitani et al. (1999). Consumed water was measured using a flow meter and energy used for pumping irrigation water and water used for washing and sterilizing seeds and facilities was calculated using the equation suggested by Kitani et al. (1999). Electricity energy consumed for air conditioning, illumination and mist irrigation system was recorded using power meter. After determining input and output energies, energy indices were obtained using the following equations (Pishgar et al., 2011):

\[
ER = \frac{OE}{IE} \quad (1)
\]

\[
NEG = OE - IE \quad (2)
\]

\[
EP = \frac{Y}{IE} \quad (3)
\]

\[
WP = \frac{Y}{W} \quad (4)
\]

Where,

\[ER\] is energy ratio or energy use efficiency, \[OE\] is output energy (MJ ha⁻¹), \[IE\] is input energy (MJ ha⁻¹), \[NEG\] is net energy gain (MJ ha⁻¹), \[EP\] is energy productivity (kg MJ⁻¹), \[Y\] is crop dry matter yield (kg ha⁻¹), \[WP\] is water productivity (kg m⁻³) and \[W\] is water used (m³).

Carbon dioxide equivalent emissions for the production, packaging, storage and transportation of chemicals were calculated using equivalent carbon emission factors suggested by Lal (2004) and C to CO₂ conversion factor, 3.67, which is the ratio of molecular weight of CO₂ to atomic weight of C. Pumping water used for irrigation and washing trays, shelves and cabinet floor was measured using flow meter and electric energy required for pumping water was calculated using the equation suggested by Kitani et al. (1999). Emission factor of 251 kg CO₂ per GJ was considered to convert the consumed electric energy to CO₂ emission (DEE, 2018). Greenhouse gas emissions resulted from production of facilities were calculated using the equation suggested by Maraseni et al. (2007). Total GHG emissions were calculated as summation of emitted GHGs from different sources and GHG emission intensity was obtained using the following equation:

\[
GHGI = \frac{TGHG}{Y} \quad (5)
\]

Where,

\[GHGI\] is greenhouse gas emission intensity (kg kg⁻¹), \[TGHG\] is total GHG emission (kg CO₂ ha⁻¹) and \[Y\] is crop dry matter yield (kg ha⁻¹). Collected data were analyzed using SAS software and Duncan’s multiple range tests was used for treatments means comparison.

RESULTS AND DISCUSSION
Fodder dry matter and water productivity
Results showed that barley cultivars and seed rates had significant effect on barley fodder dry matter production
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Table 1: Energy equivalent of different inputs.

| Input       | Energy equivalent | Reference          |
|-------------|-------------------|--------------------|
| Electricity | 12 MJ kWh⁻¹        | Kitani et al., 1999|
| Water       | 1.02 MJ m⁻³        | Shahin et al., 2008|
| Chemicals   | 85.5 MJ L⁻¹        | Kitani et al., 1999|
| Barley seed | 18.55 MJ kg⁻¹      | Kitani et al., 1999|
| Barley fodder| 17.42 MJ kg⁻¹      | Shama et al., 1989  |
| Labour      | 1.96 MJ h⁻¹        | Kitani et al., 1999|

Table 2: Variance analysis of fodder dry matter and water productivity data.

| Variation resources | Fodder dry matter (kg ha⁻¹) | Water productivity (kg m⁻³) |
|---------------------|------------------------------|-----------------------------|
| Barley cultivars    |                              |                             |
| Raihan              | 23965 a                      | 34.62 b                     |
| Behrokh             | 43096 a                      | 63.16 a                     |
| EC                  | 42516 a                      | 62.19 a                     |
| Fasih               | 42226 a                      | 62.10 a                     |
| Seed rates          |                              |                             |
| 600 (3.33 kg m⁻³)   | 33338 c                      | 48.76 c                     |
| 700 (3.89 kg m⁻³)   | 38147 b                      | 55.70 b                     |
| 800 (4.44 kg m⁻³)   | 42367 a                      | 62.09 a                     |
| Cultivars×seed rates| 0.9⁺⁺                        | 1.2⁺⁺                       |

Table 3: Means comparison of fodder dry matter and water productivity in different barley cultivars.

| Seed rates (g/tray) | Fodder dry matter (kg ha⁻¹) | Water productivity (kg m⁻³) |
|--------------------|-----------------------------|-----------------------------|
| 600 (3.33 kg m⁻³)  | 33338 c                      | 48.76 c                     |
| 700 (3.89 kg m⁻³)  | 38147 b                      | 55.70 b                     |
| 800 (4.44 kg m⁻³)  | 42367 a                      | 62.09 a                     |

Table 4: Average input and output energies in different barley cultivars.

| Barley cultivars | Input energy (MJ ha⁻¹) | Output energy (MJ ha⁻¹) |
|------------------|------------------------|-------------------------|
| Raihan           | 845278 a               | 417476 b                |
| Behrokh          | 845278 a               | 750731 a                |
| EC               | 845278 a               | 740633 a                |
| Fasih            | 845278 a               | 735585 a                |

Table 5: Average input and output energies in different seed rates.

| Seed rates (g/tray) | Input energy (MJ ha⁻¹) | Output energy (MJ ha⁻¹) |
|--------------------|------------------------|-------------------------|
| 600 (3.33 kg m⁻³)  | 752528 c               | 580754 c                |
| 700 (3.89 kg m⁻³)  | 845278 b               | 664528 b                |
| 800 (4.44 kg m⁻³)  | 938028 a               | 738037 a                |

(p<0.01), but dry matter was not affected by interaction between these two factors (Table 2). Significant effect of barley cultivars on fodder dry matter has been also reported by Emam (2016) and Al-Karaki and Al-Momani (2011). Barley seed rate significant effect on dry matter has been reported by El-Morsy et al. (2013). Results of data analysis showed that barley cultivars and seed rates had significant effect (p<0.01) on water productivity of barley fodder production (Table 2). Since barley fodder yield was affected by barley cultivars and seed rates, significant influence of barley cultivars and seed rates on barley fodder water productivity was expected. Emam (2016) and Al-Karaki and Al-Momani (2011) also reported that barley cultivars had significant effect on water productivity of barley fodder production. Means comparison indicated that Behrokh cultivar produced the maximum dry matter (43096 kg ha⁻¹) and the minimum dry matter (23965 kg ha⁻¹) was related to Raihan cultivar (Table 3). Difference between dry matters produced by Behrokh and Raihan cultivars was statistically significant, but there was no significant difference among Behrokh, EC and Fasih cultivars for dry matter production. These results proved that Raihan was not a proper barley cultivar for barley green fodder production in hydroponic condition. Al-Karaki and Al-Momani (2011) reported the maximum barley green fodder production of 281000 kg ha⁻¹ (about 34000 kg ha⁻¹ dry matter) in Jordan which was lower than what we produced in this study. Means comparison of water productivity in different barley cultivars indicated that Raihan cultivar which had the lowest dry matter yield, had also the minimum water productivity (34.62 kg m⁻³) with a big difference compared to the other cultivars (Table 3). Behrokh cultivar had the maximum water productivity (63.16 kg m⁻³) among the cultivars tested; however, the difference between this cultivar, EC and Fasih was not significant. Al-Karaki and Al-Momani (2011) reported the maximum water productivity of 81 kg m⁻³ for a local barley variety in hydroponic condition in Jordan.

Different seed rates also produced statistically different amount of fodder dry matter (Table 4). The highest amount of dry matter (42367 kg ha⁻¹) was obtained from the highest amount of seed rate (800 g/tray) and the lowest seed rate (600 g/tray) produced the lowest amount of fodder dry matter (33338 kg ha⁻¹). El-Morsy et al. (2013) also reported that barley seed rate had significant effect on barley fresh and dry fodder yields so that fresh and dry fodder yields increased with increasing seed rate. Water productivity increased with increasing seed rate so that 600 g/tray had the minimum water productivity (48.76 kg m⁻³) and the maximum water productivity (62.09 kg m⁻³) was related to the seed rate of 800 g/tray (Table 4). Since water productivity of barley forage production in field condition is less than 1 kg m⁻³ in Iran, producing more than 63 kilograms barley...
fodder dry matter by consuming only one cubic meter water in hydroponic condition in semi-arid climate condition of Iran is a big advantage for hydroponic agricultural system.

Input and output energies

Results of input and output energies means comparison proved that there was no significant difference between cultivars for input energy; while, output energy of Raihan cultivar was significantly lower than those of Behrokh, EC and Fasih (Table 5) because of its lower dry matter yield. Seed rate had significant effect on both input and output energies so that input and output energies increased with increasing seed rate (Table 6). Results also showed that consumed energy in producing barley fodder using these cultivars and seed rates in hydroponic condition was higher than the produced energy.

Energy indices and GHG emission intensity

Variance analysis of energy ratio (energy efficiency), net energy gain, energy productivity and GHG emission intensity data revealed that all these parameters were significantly affected by barley cultivar, but seed rate had significant impact only on the GHG emission intensity (Table 7). Interaction effect of barley cultivars and seed rates was significant only on GHG emission intensity. Results also proved that the maximum energy ratio, net energy gain and energy productivity was related to Behrokh cultivar; while, there was no significant difference between Behrokh, EC and Fasih (Table 8). Raihan cultivar had the minimum energy ratio, net energy gain and energy productivity which were significantly different from those of Behrokh, EC and Fasih. Raihan cultivar had the maximum GHG emission intensity (1.7 kg CO$_2$e kg$^{-1}$ dry matter) and

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**Table 7:** Variance analysis of energy indices and GHG emission intensity data.

| Variation resources | Energy ratio | Net energy gain | Energy productivity | GHG emission intensity |
|---------------------|--------------|-----------------|---------------------|------------------------|
| Barley cultivars    | 74.06**      | 70.61**         | 74.09**             | 111.61**               |
| Seed rates          | 0.13m        | 0.74m           | 0.14m               | 20.75**                |
| Cultivars x seed rates | 1.21m       | 0.98m           | 1.21m               | 3.15**                 |

m: Non-significant; **: significant at p<0.01.

**Table 8:** Means comparison of energy indices and GHG emission intensity in different barley cultivars.

| Barley cultivars | Energy ratio | Net energy gain (MJ ha$^{-1}$) | Energy productivity (kg MJ$^{-1}$) | GHG emission intensity (kg CO$_2$e kg$^{-1}$ dry matter) |
|------------------|--------------|---------------------------------|-----------------------------------|--------------------------------------------------------|
| Raihan           | 0.49 b       | -427802 b                       | 0.028 b                           | 1.70 a                                                 |
| Behrokh          | 0.89 a       | -94547 a                        | 0.051 a                           | 0.89 b                                                 |
| EC               | 0.88 a       | -104644 a                       | 0.050 a                           | 0.91 b                                                 |
| Fasih            | 0.87 a       | -109693 a                       | 0.050 a                           | 0.92 b                                                 |

a, b: Averages with different letters in each column are statistically different at p<0.05.

**Table 9:** Means comparison of energy indices and GHG emission intensity in different seed rates.

| Seed rates (g/tray) | Energy ratio | Net energy gain (MJ ha$^{-1}$) | Energy productivity (kg MJ$^{-1}$) | GHG emission intensity (kg CO$_2$e kg$^{-1}$ dry matter) |
|---------------------|--------------|---------------------------------|-----------------------------------|--------------------------------------------------------|
| 600 (3.33 kg m$^{-2}$) | 0.77 a       | -171773 a                       | 0.044 a                           | 1.26 a                                                 |
| 700 (3.89 kg m$^{-2}$) | 0.79 a       | -180749 a                       | 0.045 a                           | 1.09 b                                                 |
| 800 (4.44 kg m$^{-2}$) | 0.79 a       | -199991 a                       | 0.045 a                           | 0.97 c                                                 |

a, b, c: Averages with different letters in each column are statistically different at p<0.05.
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