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Effect of different sowing densities on biomass production and nutritive value of barley green fodder grown in a hydroponic system

Wpływ różnej gęstości wysiewu nasion na produkcję biomasy i wartość pokarmową zielonki jęczmiennej uprawianej w systemie hydroponicznym

Abstract. We conducted this study to investigate the impact of various seed ratios on the growth rate, performance, nutritive value, and digestibility of fodder grown in a hydroponic system. Seeds were applied at 1000 g for high seed density treatment (HSD: 4.761 kg m^{-2}) and 750 g for low seed density treatment in each tray (LSD: 3.571 kg m^{-2}). Three harvest times (8th, 9th, and 10th day of germination) were evaluated to measure the shoot height, root length, and fodder yield. Nutritive value and *in vitro* digestibility were determined at 10 days of harvesting. The HSD treatment had higher fresh weight and root length but lower shoot height throughout the harvest time. A higher green fodder yield, dry matter content, dry matter yield, crude protein yield, and lower contents of dry matter and crude protein loss were observed in HSD treatment. The fodder of LSD treatment had a higher content of ether extract, crude ash, crude fibre, and a higher digestibility rate but a lower content of neutral detergent fibre and acid detergent fibre compared to those in the HSD fodder. Taking performance factors into account, the more efficient fodder seems to be barley green fodder with high-density sowing, but considering parameters regarding the nutritive value and feed digestibility such as NDF, ADF, and IVDMD, the more efficient fodder appears to be barley fodder with low-density sowing.

Keywords: barley fodder, digestibility, nutritive value, performance, seed density

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INTRODUCTION

Nowadays, livestock production systems face difficulties adapting to climate change's consequences, which negatively affect feed and water supply [Godde et al. 2021]. Under a global warming scenario, the effects of drought are more likely to worsen in the future [Mukherjee et al. 2018]. Drought and water scarcity are concurrently observed in arid and semi-arid regions. Considering climate change and drought, water conservation and sustainable water consumption are critical in agricultural and landscape irrigation [Pereira et al. 2012]. The hydroponic system effectively reduces water wastage by directly applying it to the roots and frequently recycling and reusing it more than once. Hydroponic fodder production requires just 1.5–2 l of water per 1 kg, whereas traditional agricultural conditions need 160 l, 85 l, and 73 l of water to grow 1 kg of green fodder for Rhodes grass, lucerne, and barley, respectively [Shit 2019].

Incubation rooms or hydroponic systems may grow green food without soil or fertilizers. For optimal germination, it is crucial to maintain the appropriate temperature, humidity, and light conditions [Fazaeli et al. 2011]. If these parameters are met, producing green feed becomes considerably more straightforward [Sneath and McIntosh 2003, Hussain et al. 2014]. As the seeds germinate, the roots establish a strong connection and create a dense layer, while the stems grow to 20–23 cm within 7–10 days. Additionally, the stems contain 6–8 times more fresh fodder weight than the seeds. One of the most significant benefits of this kind of production system is that it may be utilized for green fodder production in a sanitary environment without chemicals like herbicides, insecticides, and fungicides [Sneath and McIntosh 2003, Sarıçiçek et al. 2018]. The nutritional value of hydroponically grown green fodder has been reported to be higher after 7 days of growth [Akbağ et al. 2014, Saidi and Omar 2015]. Within 7–8 days after planting, energy levels and organic matter contents decreased linearly as structural carbohydrates, including neutral detergent fibre (NDF), acid detergent fibre (ADF), and crude fibre (CF) content increased [Fazaeli et al. 2012, Gebremedhin et al. 2015]. A low dry matter content might be an important limitation for animal nutrition and fodder production. Also, fungal and mould proliferation can occur in fodder because of its high moisture content [Sneath and McIntosh 2003]. On the other hand, using green fodder with low dry matter for animal nutrition might be challenging [Gümüş and Bayir 2020]. A limited number of studies have focused on comparing the green fodder performance of different seed densities of barley grown in a hydroponic system, and not much data is available on their nutritive value. Therefore, this study aimed to compare the growth rate, yield, nutritive value, and digestibility of barley fodder, considering different seed densities during planting and different lengths of the growth period.

MATERIALS AND METHODS

The experiment was conducted in a steel hydroponic chamber in the Center for Agriculture, Livestock and Food Research, Burdur Mehmet Akif Ersoy University (Southern Türkiye, 30°53'E, 36°53'N and 950 m above sea level) in 2021. The intensive hydroponic system was constructed by using a steel stand, size 2.80 m × 9 m × 7 m (H × L × W), equipped with seven shelves having a total capacity of 196 polyethylene trays (70 cm × 30 cm × 5 cm; 0.21 m^2). Hydroponic conditions with a temperature of 18–19°C, relative humidity of 60%, lighting time of 12 h using yellow colour lights, and irrigation time and frequency of 90 s every 2 h were applied during the research period. Before planting, production chambers, trays, irrigation systems, and essential instruments underwent sterilization using a 10% formaldehyde concentration. Every day, 50 ml of sodium hypochlorite was added to the irrigation system water to minimize the potential growth of mould. Tap water was used for irrigation.

The treatments differed in the density of the seed whilst planting and were designed as high-seed density treatments in which 1000 g of seed was applied to each tray (HSD: 4.761 kg m^{-2}) and low-seed density treatments in which 750 g of seed was applied to each tray (LSD: 3.571 kg m^{-2}). All experiments were carried out in 7 replicates. Fourteen trays (2 groups × 7 subgroups) were used in the steel hydroponic chamber. Seeds were pre-soaked in water separately for 24 h to clean the seeds from wastes, straw, etc., and to accelerate the germination process. The trays were placed on the shelves of the hydroponic chamber and allowed to grow for 10 days. The impact of different plant growth periods (8th, 9th, and 10th day of germination) on the shoot height, root length, and fresh weight were examined in the study. To determine the growth rate, the shoot height and root length of six plants randomly selected from each tray were measured using a tape measure from day 8th until the harvest day (day 10th). From each tray, three samples of fodder (right corner, left corner, and middle of each tray) were weighed to measure the fresh weight (FW). Samples were collected from each tray from the highest to the lowest point. The sampling area was square-shaped with dimensions of 10 cm × 10 cm.

The collected samples were dried, grounded and analyzed after 4 days of collection. The feed samples were analyzed based on the Association of Official Analytical Chemists [AOAC 2005] methods: the content of dry matter (DM, method 934.01), ash (method 942.05), ether extract (EE, method 920.39) and nitrogen (method 954.01). Crude fibre (CF), neutral detergent fibre (NDF), and acid detergent fibre (ADF) contents were determined following the ANKOM (Ankom^{200} fibre analyzer, Ankom Technology Corp., Fairport, NY) methods [Van Soest et al. 1991]. Evaluation of the *in vitro* dry matter digestibility (IVDMD) of fodders was carried out using the Daisy^{II} incubation (Daisy^{II} Incubator, ANKOM Technology, NY, US) method as an *in vitro* technique [Vogel et al. 1999].

The statistical analyses were conducted using the IBM SPSS program, version 21 [IBM 2021]. An independent-sample t-test was used to determine the effects of seed density on the growth rate, performance, nutritive value, and digestibility of fodder. Duncan's multiple comparisons were used to compare differences between groups, and differences are considered significant when $P < 0.05$.

RESULTS

As shown in Table 1, there was no significant difference in the shoot height and root length between the two groups at d 8 and 9 of harvesting. The shoot heights ($P = 0.02$) were significantly higher in the LSD treatment than those in the HSD treatment, but root length ($P = 0.03$) was significantly lower in the LSD treatment on the 10th day of harvesting. FW increased along with the postponement of harvest time. HSD treatment resulted in a significantly higher yield of FW compared to LSD fodder. As shown in Table 2, there were significant differences between groups in terms of the green fodder yield (GFyield; kg m^{-2}; $P = 0.009$), dry matter yield (DMyield; kg m^{-2}; $P = 0.001$), and crude protein yield

(CPyield; g m^{-2}; P = 0.001). However, DM content (P = 0.61), dry matter losses (DMloss; P = 0.69) and crude protein losses (CPloss; P = 0.30) were not affected in the current study. As shown in Table 3, there were significant differences between both treatments of barley fodder in terms of their chemical composition. Significantly higher contents of EE (P = 0.03), CF (P = 0.02), and higher IVDMD coefficient (P = 0.02) but lower ADF (P = 0.02) were stated in LSD treatment. There was no significant difference in the content of ash (P = 0.35) or NDF (P = 0.29) between groups.

Table 1. The growth rate of barley green fodders of high- and low-seed density treatments depending on the time of harvesting after germination

Days	Shoot height (cm)			Root length (cm)			Fresh weight (kg/tray)		
	HSD	LSD	P value	HSD	LSD	P value	HSD	LSD	P value
8	5.38	5.54	0.60	1.70	1.40	0.06	4.98	4.10	0.002
9	7.46	7.68	0.51	2.01	1.97	0.78	5.50	4.46	0.001
10	9.76	10.5	0.02	2.24	2.03	0.03	5.94	4.92	0.009

HSD – high-density seed treatment, LSD – low-density seed treatment

Table 2. Performance of barley green fodders of high- and low-seed density treatments

Treatments	GFyield (kg m^{-2})	DM (%)	DMyield (kg m^{-2})	DMloss (%)	CP (%), DM basis	CPyield (g m^{-2}) DM basis	CPloss (%), DM basis
HSD	28.30	9.84	2.77	33.97	16.15	446.94	7.46
LSD	23.43	8.67	2.03	35.50	15.65	305.61	12.45
P value	0.009	0.61	0.001	0.69	0.52	0.001	0.30

GFyield – green fodder yield; DM – dry matter content; DMyield – dry matter yield; DMloss – dry matter loss; CP – crude protein content; CPyield – crude protein yield; CPloss – crude protein loss
HSD – high-density seed; LSD – low-density seed

Table 3. Nutritive value and *in vitro* dry matter digestibility of barley green fodders of high- and low-seed density treatments, DM basis

Treatments	EE (%)	Ash (%)	CF (%)	NDF (%)	ADF (%)	IVDMD (%)
HSD	2.64	3.00	18.15	56.02	26.17	80.64
LSD	2.96	3.22	20.67	54.10	24.39	83.03
P value	0.03	0.35	0.02	0.29	0.02	0.02

EE – ether extract; CF – crude fibre, ADF – acid detergent fibre, NDF – neutral detergent fibre, IVDMD – *in vitro* DM digestibility
HSD – high-seed density treatment, LSD – low-seed density treatment

DISCUSSION

Many factors, such as the type and ratio of seed [Afzalinia and Karimi 2020], harvest time [Akbağ et al. 2014], and fertilizing [Akman et al. 2021] can affect the shoot height and root length of fodder produced by a hydroponic system. Interestingly, in the current study, shoot height was higher in the LSD group than in the HSD group throughout the study. The current findings indicate that LSD exhibited a greater shoot height and shorter root length on days 8th, 9th, and 10th of germination compared to HSD (Tab. 1). The research conducted by [El-Morsy et al. 2013] demonstrated that increasing the density of seeds had a positive effect on the height of shoots and the length of roots. Emam [2016] stated that barley fodder's (Giza 127 variety) shoot height on day 7th of harvesting reached 10.10 cm, which was more significant than our findings. The root length ranged from 1.40 cm to 2.24 cm in the current study, which is aligned with the previous study's findings [Karaşahin 2016]. The author [Paudel et al. 2021] mentioned that the plant height of barley fodder was the highest with a seed rate of 6 kg m^{-2} and the lowest with a seed rate of 4 kg m^{-2}.

Hydroponic systems have offered an alternative to traditional agriculture by enabling year-round production of green fodder, regardless of the climate conditions [Naik et al. 2012, Afzalinia and Karimi 2020]. The higher FW biomass in HSD treatment was recorded at 4.98, 5.50 and 5.94 kg per tray on days 8th, 9th, and 10th of harvesting compared to LSD, respectively. El-Morsy et al. [2013] achieved 3.5 kg and 6.4 kg FW of barley fodder at seed rates of 5 kg m^{-2} and 7 kg m^{-2}, respectively. A previous study by Al-Karaki and Al-Hashimi [2012] showed that the FW of barley fodder ranged from 3.74 to 6.0 kg from one kg of barley seeds. In comparison, the average FW was reported to be 2.71 kg and 3.16 kg per tray on day 10 of harvesting at a planting amount of 450 g seed, equivalent to seed rates of 4.0 kg m^{-2} [Al-Momani and Al-Karaki 2011]. After 8 days of planting, Emam [2016] observed 9.74 kg FW of barley fodder (*Giza 128*) at a seed rate of 10 kg m^{-2}. It was also found that barley fodder had higher FW at seed rates of 10 kg m^{-2} (FW: 9.5 kg) than at seed rates of 5 kg m^{-2} (FW: 3.5 kg) on d 8 of harvesting [El-Morsy et al. 2013].

After 10 days of planting, HSD treatment showed higher GFyield ($P = 0.009$; 28.30 vs. 23.43 kg m^{-2}; Tab. 2), DMyield ($P = 0.001$; 2.77 vs. 2.03 kg m^{-2}; Tab. 2), DM content ($P = 0.61$; 9.84 vs. 8.67%; Tab. 2) and crude protein yield ($P = 0.001$; 446.94 vs. 305.61 g m^{-2}; Tab. 2) than LSD fodder. Lower dry matter loss ($P = 0.69$; 33.97 vs. 35.50%; Tab. 2) in the HSD treatment compared to the LSD treatment was mainly due to higher DM content in HSD cultivars ($P = 0.61$; 9.84 vs. 8.67%; Tab. 2). The findings line up with the results reported by Assefa et al. [2020] indicating that higher seed rates (42.94 kg m^{-2}) resulted in greater green fodder yield compared to medium (33.41 kg m^{-2}) or low seed rates (24.92 kg m^{-2}). Similar results were previously indicated by Paudel et al. [2021], who found that green fodder yield increased from 16.46 to 28.09 kg m^{-2} along with increasing seed density. The results of the current study indicated that a reduction in seed density from 4.761 to 3.571 kg m^{-2} led to a decline in DM content. The finding contradicts the results reported by El-Morsy et al. [2013], who observed that increasing seed density decreased DM content. In the current study, DM content decreased along with DM loss in the LSD treatment, where the reduction might be attributed to the lower conversion of seeds into fodder due to the slower germination rate of seeds.

The HSD treatment exhibited a greater CP content ($p = 0.52$; 16.15 vs. 15.65%; Tab. 2) compared to the LSD treatment. Our outcomes were more significant than those documented by Fazaeli et al. [2011], who found that the CP content of barley fodder ranged from 13.7% to 14.5%. Contrary to the current study, Saadi and Omar [2015] showed that CP was 19.8% in barley fodder. It is worth noting that the findings were inconsistent, possibly due to variations in the research conditions, seed type, seed quality, addition of liquid fertilizer, and harvesting time. Research conducted by Akbağ et al. [2014] reported that the effects of harvesting time on fodder CP with slightly higher crude protein content at day 13 (17.6%) than on day 7 (17.1%) but lower than at day 10 (18.2%). One possible reason for the higher protein content in the fodder might be young sprouts' more remarkable photosynthesis ability and their higher DM losses [Girma and Gebremariam, 2018]. The study conducted by El-Morsy et al. [2013] highlighted that observed improvement in enzyme activity during germination could probably be associated with an elevated concentration of CP in the fodder, resulting in probable changes in the amino acid profile. LSD treatment led to a higher EE (P = 0.03; 2.96 vs. 2.64%; Tab. 3) than HSD treatment. EE content increased when the seed rate decreased from 7.6 kg m^{-2} to 5.6 kg m^{-2} [Assefa et al. 2020]. The EE content of hydroponic fodder increases due to increased structural lipids and chlorophyll as the plant grows [Gebremedhin et al. 2015]. The LSD treatment showed a slightly higher ash content compared to the HSD treatment. Compared with the original barley seeds, both treatments had increased ash content. Researchers evaluating barley fodder also found similar results [Peer and Leeson 1985, El-Morsy et al. 2013]. The increase in ash content may be attributed to the enhanced absorption of minerals by the roots [Morgan et al. 1992]. According to Fazaeli et al. [2012], fodder has a notably higher iron, zinc, and calcium concentration than seeds.

LSD treatment had higher CF (P = 0.02; 20.67 vs. 18.15%; Tab. 3) and a higher IVDMD coefficient (P = 0.02; 83.03 vs. 80.64 %; Tab. 3) but lower NDF (P = 0.29; 54.10 vs. 56.02%; Tab. 3) and ADF contents (P = 0.02; 24.39 vs. 26.17%; Tab. 3) than HSD treatment. Emam [2016] found that the CF content of barley fodder ranged from 8.13% to 12.4% of DM, which is lower than our results. The mean content of NDF [Akbağ et al. 2014] in barley fodder ranged from 51.01% to 54.05%, similar to the current study's range (54.10–56.02% DM basis). In a previous study [Gümüş and Bayir 2020], we noted that hydroponic barley fodder had 20.89% ADF content, which is lower than current results. The increase in the percentage of NDF and ADF in the HSD treatment could be attributed to an increase in seed density. The ADF content of forage directly influences *in vitro* digestibility. Compared to the HSD treatment, LSD fodder had a higher digestibility rate due to the lower ADF content.

CONCLUSION

HSD treatment had a higher root length and yielded a higher fresh weight mass as compared to those in the LSD treatment. The HSD treatment exhibited increased yields of green fodder, dry matter, and crude protein compared to the LSD treatment. However, the LSD treatment showed a higher content of EE, ash, and CF with a lower NDF and ADF value. It affected the *in vitro* digestibility coefficient, which was significantly higher in the LSD treatment compared to the HSD treatment. Taking performance factors into account, the most efficient fodder seems to be barley green fodder sown at high seed density, but considering parameters regarding the nutritive value and feed digestibility such as NDF, ADF, and IVDMD, the more efficient fodder appears to be barley green fodder with low sowing density. However, further research is needed to determine the optimal use of seed densities in hydroponic systems to produce green fodder.

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