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Barley (*Hordeum vulgare* L.) Cultivars Dry Forage Yield and Whole-Crop Silage Quality as Affected by Interaction of Drought and Nitrogen Fertigation

Siavash Bardehji[1], Hamid Reza Eshghizadeh[1]*, Morteza Zahedi[1], and Mehrdad Mahlooji[2]

Abstract

Barley silage is a cornerstone of sustainable livestock feed, yet its production faces mounting pressure from water scarcity and variable growing conditions. The objective of this study was to explore how soil moisture conditions (50% and 85% soil-water depletion) and nitrogen (N) fertigation (0 and 62.5 kg N/ha as urea, 46-0-0) shape the dry forage yield (DFY) and silage quality of 10 barley cultivars across two distinct planting environments (E1: 22 October 2017; E2: 4 March 2018). Conducted in field trials in 2017 and 2018, our results reveal a major finding of a striking duality: N fertigation boosted dry matter yield (DMY) by 1474 kg/ha under well-watered conditions, yet reduced it by 399 kg/ha under drought stress. This interaction also influenced silage quality, with drought stress elevating silage dry matter (SDM), neutral detergent fiber (NDF), and propionic acid while diminishing digestibility (DIG), relative feed value (RFV), and lactic acid content, whereas N fertigation lowered NDF and, under adequate moisture, enhanced DIG and RFV. The applied implication is that these insights enable optimized N management strategies to enhance barley silage yield and quality in water-limited regions.

Keywords: Barley cultivars, Digestibility, Fatty acids, Nitrogen, Soil moisture condition.

Abbreviations: ADF, acid detergent fiber; DDM, digestible dry matter, DMY, dry matter yield; DIG14, digestibility in 14 hours; DIG30, digestibility in 30 hours; NDF, neutral detergent fiber; NE_L, net energy for lactation; RFV, relative feed value; SDM, silage dry matter content; TSC, total soluble carbohydrates; RDP, rumen degradable protein; MAD, maximum allowable depletion; SAW, soil available water.

1- Introduction

Water scarcity, driven by dwindling rainfall, urbanization, industrialization, and climate change, poses a growing threat to irrigation-dependent agriculture in arid and semi-arid regions (Mancosu et al., 2015; Carraro and Di Iorio, 2022). This challenge has severely constrained

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[1] Department of Agronomy and Plant Breeding, College of Agriculture, Isfahan University of Technology, Isfahan, Islamic Republic of Iran.
[2] Horticulture Crops Research Department, Isfahan Agricultural and Natural Resources Research and Education Center, AREEO, Isfahan, Islamic Republic of Iran.
*Corresponding author; e-mail: hr.eshghizadeh@iut.ac.ir

forage production for livestock, with high-water-demand crops like corn silage and alfalfa hay losing viability due to their warm-season growth patterns (Weller et al., 1992). Barley (*Hordeum vulgare* L.), however, emerges as a resilient alternative, thriving in adverse conditions such as drought, salinity, and heat stress (Feiziasl et al., 2022; Fischbeck, 2002). Its adaptability to autumn and early spring planting allows it to capitalize on sparse rainfall, making it a staple in water-limited environments (Bardehji et al., 2021). Globally, over 70% of barley production supports livestock feed (Tricase et al., 2018), serving diverse species and enhancing animal performance through high-quality whole-crop silage (Borowiec et al., 1998; Wallsten and Hatfield, 2016). As an energy and protein source for milking herds, barley silage holds untapped potential to boost farm profitability by improving yield and quality (Anderson and Schroeder, 1999; Sun et al., 2021; Flaten et al., 2019).

Despite its drought tolerance, barley is not immune to water deficit, with drought stress specifically causing 15–45% reductions in both grain and forage yield percentages under varying stress intensities (Albrizio et al., 2010; Bardehji et al., 2021). These losses stem from disrupted water and nutrient uptake (Mahlooji et al., 2018), with impacts varying across species and cultivars. The effects on silage quality remain contentious: some report that drought stress lowers leaf-to-stem ratios and digestibility while increasing crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) (Farahani and Chaichi, 2013; Uzun et al., 2017), whereas others find ADF unaffected or fiber degradability unchanged (Islam et al., 2012; Ferreira et al., 2021). Nitrogen (N) fertigation offers another lever to enhance forage outcomes. Research demonstrates linear yield gains with N rates up to 132 kg/ha (Collen, 2006), alongside increases in crude protein, digestibility, and leaf area, and reductions in fibrous components (Nematpour et al., 2021; Vos et al., 2005). Yet, N effects on silage traits like water-soluble carbohydrates, buffering capacity, and crude fiber remain inconsistent (Tremblay et al., 2005; Brezink et al., 2002; Carr et al., 2004).

These conflicting findings, coupled with recent studies (2021–2025) on barley under deficit irrigation and nitrogen management (e.g., Sabra et al., 2023; Al-Menaie et al., 2024; Bardehji, et al., 2025), highlight a critical knowledge gap: while these works advance understanding of individual effects on grain yield, the interactive impacts of soil moisture and N fertigation on whole-crop silage yield and quality—across diverse genotypes in water-limited regions—remain underexplored.

This study aims to assess the yield response of different barley genotypes to varying soil moisture conditions and urea fertigation and evaluating the whole-crop silage quality, providing insights to optimize production in drought-prone regions.

2- Materials and Methods

2.1 Experimental Design and Plant Material

This study was conducted at the Isfahan University of Technology research farm (Lavark) in Najaf Abad, Iran (32°32′ N, 51°23′ E, 1630 m elevation) under two planting dates that established distinct environmental conditions due to seasonal differences in climate and photoperiod: E1 (fall planting on 22 October 2017) and E2 (spring planting on 4 March 2018). A split-split plot design within a randomized complete block framework, replicated thrice, was employed in each planting date. Main plots consisted of two soil moisture levels—control (50% depletion) and water deficit (85% depletion)—while subplots featured two nitrogen fertigation levels (0 and 62.5 kg N/ha as urea, 46-0-0). This N rate was selected based on preliminary soil tests (Table 1), regional fertilizer recommendations for barley in semi-arid Iran, and previous studies indicating significant yield responses at moderate rates (e.g., 50–80 kg N/ha) under water-limited conditions. Sub-sub plots included 10 barley cultivars representing a diverse range of drought tolerance levels (high, medium, and low) and spike row numbers (two- and six-rowed types) (Table S1). Each sub-sub plot comprised 13 rows, 2 m long, spaced 15.4 cm apart, with a planting density of 360–370 plants/m², averaging 1461 plants per plot and 112 per row, sown by hand.

2.2 Soil and Weather Conditions

Soil physical and chemical properties are detailed in Table 1. Monthly weather data during the growing seasons were sourced from the Najaf Abad Synoptic Weather Station (Table 2).

2.3 Soil Moisture and Nitrogen Treatments

Soil moisture treatments were based on the maximum allowable depletion (MAD) of soil available water (SAW), ranging from 0.03 to 1.5 MPa. Control (55% ± 5% depletion) and water deficit (85% ± 5% depletion) levels were set, monitored by measuring soil moisture at root depth throughout growth.

Soil moisture was determined gravimetrically by periodic sampling (immediately before each scheduled irrigation) from the 5–30 cm depth after removing the dry surface layer (0–5 cm) to avoid measurement error. At least three subsamples were taken from both the control and water-deficit regimes in each plot, placed immediately in sealed nylon bags to prevent moisture loss, and transported to the laboratory. In the laboratory, 100 g of fresh soil from each subsample was weighed and dried in a microwave oven for 25 min until constant weight was reached. Soil moisture content was then calculated on a gravimetric basis. These measured values were compared with the pre-determined field capacity (θ_{FC} = 25%) and permanent wilting point (θ_{PWP} = 16%) obtained from the soil laboratory of the Department of Soil Science, College of Agriculture, Isfahan University of Technology. The MAD thresholds were calculated as:

$$\theta irrig = \theta_{FC} - (\theta_{FC} - \theta_{PWP}) \times MAD$$

, where θirrig is the soil-water content at irrigation (m^3/m^3), θ_{FC} is field capacity (%),θ_{PWP} is wilting point (%), and MAD reflects depletion levels (Allen et al., 1998). Irrigation depth was determined by:

$$Dirrig = (\theta_{FC} - \theta_{avg}) \times D_{rz},$$

with Dirrig as depth (cm), D_{rz} as root zone depth (cm), and θ_{avg} as pre-irrigation soil-water content (m^3/m^3) (Nematpour et al., 2020).

Irrigation occurred via drip tapes (16 mm diameter, 15 cm emitter spacing, 1.3 L/h flow), with tapes 30 cm apart, servicing two rows each. Water deficit began at Zadoks growth stages 13 (3 leaves), after uniform irrigation at 55% MAD. Urea was applied in three equal doses (0 or 20.83 kg N/ha) at Zadoks codes 13, 30 (stem elongation), and 50 (heading) via fertigation (Zadoks et al., 1974).

2.4 Yield Measurement and Silage Preparation

At the soft-dough stage (Zadoks code 85), plants from central rows were harvested and weighed. Subsamples (100 g) were oven-dried at 65°C for 48 h to determine dry matter percentage. Remaining material was chopped (~2 cm) using a two-row maize chopper (Barchinkar Industrial Co., Yazd, Iran) and packed into 240 three-liter PVC mini-silos at a packing density of 550 kg fresh matter m^{-3} (2 environments × 2 moisture levels × 2 nitrogen levels × 10 cultivars × 3 replicates). Silos were sealed after air removal with CO_2 and stored at room temperature for 90 days.

2.5 Silage Analysis

After 90 days, mini-silos were opened, and silage traits—pH, dry matter, ash, ADF, NDF, DDM, NEL, RFV, crude protein, total soluble carbohydrates (TSC), digestibility, and fatty acids—were assessed as follows:

2.5.1 pH

Fresh silage (30 g) was blended with 270 mL distilled water, filtered through double-layered cheesecloth, and pH measured with a manual pH meter (Model 8601 AZ, China) (Nematpour et al., 2020).

2.5.2 Dry Matter and Ash

Silage (200 g) was dried at 65°C for 48 h to calculate dry matter. Ash was determined by incinerating dried samples at 550°C for 12 h, calculated as: %Ash = (ash weight/sample weight) × 100.

2.5.3 ADF, NDF, DDM, NEL, and RFV

ADF and NDF were analyzed using an ANKOM 220 Fiber Analyzer (USA, Patent 5,370,007) per Van Soest et al. (1991). DDM, NEL, and RFV were derived from Yolcu et al. (2008):

$$\text{DDM (\%DM)} = 88.9 - (0.779 \times \text{ADF});$$

$$\text{DMI (\%BW)} = 120/\text{NDF};$$

$$\text{RFV} = (\text{DMI} \times \text{DDM})/1.29;$$

$$\text{NEL } (\text{Mcal kg}^{-1}) = (1.044 - 0.0119 \times \text{ADF}) \times 2.205.$$

2.5.4 Crude Protein and TSC

Crude protein was calculated as 6.25 × total nitrogen, measured via Biancarosa et al. (1998). TSC was quantified by Johnson et al. (1966), extracting 0.5 g silage with ethanol, reacting with anthrone, and reading absorbance at 625 nm.

2.5.5 Digestibility

Dried, milled silage (0.5 g) was incubated in rumen bags within a fistulated cow for 14 and 30 h, then dried at 65°C for 48 h. Digestibility was calculated as: ((initial weight - final weight)/initial weight) × 100 (Vanzant et al., 1998).

2.5.6 Fatty Acids

Fatty acids (acetic, lactic, propionic, butyric) were analyzed in four cultivars selected to represent a range of genetic diversity (including local Iranian, improved, and international varieties) and chosen based on their contrasting responses in preliminary yield and quality assessments (Behrokh, M-93-16, Goharan, RGT-Planet) under normal nitrogen using HPLC (HP 1090 Series, USA) per Arnetol et al. (2008).

2.6 Statistical Analysis

For all traits except fatty acids, a combined analysis of variance was performed on split-split plot data (2 moisture levels × 2 nitrogen levels × 10 cultivars × 3 replicates) using SAS 9.4 (SAS Institute, Cary, NC, USA). For fatty acids, analysis used split plots (2 moisture levels × 4 cultivars × 3 replicates). Means were compared with the LSD test ($P \leq 0.05$), and histograms were drawn in Microsoft Excel 2016.

3- Results

3-1- Main results

Soil moisture conditions (50% and 85% depletion), nitrogen levels (0 and 62.5 kg N/ha as urea), and cultivars affected nearly all traits (Table S2, Table 3). Exceptions included NEL and acetic acid, which showed no cultivar variation. Overall, soil moisture emerged as the dominant limiting factor, overriding nitrogen and cultivar effects for most yield- and quality-related traits. Water deficit stress (85% depletion) reduced DMY, crude protein, DIG14, DIG30, DDM, RFV, NEL, acetic acid, lactic acid, and butyric acid, but elevated SDM, ash, and propionic acid relative to control conditions (50% depletion) (Tables 3 and 9). This shift indicates a clear trade-off between biomass production and forage nutritive value under drought stress, accompanied by altered fermentation profiles.

Nitrogen application boosted most traits—DMY, crude protein, DIG14, DIG30, DDM, RFV and NEL —while reducing SDM, TSC, ADF, NDF, and pH (Table 3). These results confirm the compensatory role of nitrogen in improving forage quality, particularly under favorable soil moisture conditions.

Cultivar differences were notable, with Goharan showing the highest TSC and CB-84-10 exhibiting the lowest ADF and highest DIG14 (Table 3). These contrasting responses highlight cultivar-specific strategies, where Goharan favors carbohydrate accumulation, while CB-84-10 exhibits superior fiber digestibility, making it more suitable for high-quality forage production.

3-2 Soil Moisture × Nitrogen Interaction

Soil moisture and nitrogen interacted significantly on DMY ($P \leq 0.01$; Table S2). Nitrogen boosted DMY by 1474 kg/ha under control conditions but reduced it by 399 kg/ha under water deficit stress. The highest DMY (11,580 kg/ha) occurred with control soil moisture and nitrogen, while the lowest (6995 kg/ha) was under water deficit without nitrogen (Fig. 1). This crossover interaction demonstrates that nitrogen efficiency is strongly moisture-dependent and may become counterproductive under severe drought.

3-3 Soil Moisture × Cultivar Interaction

Under control soil moisture, cultivars varied significantly in DMY, but under water deficit, only RGT-Planet differed (Table 4). This indicates a convergence of cultivar performance under stress, except for RGT-Planet, which maintained partial yield stability. Water deficit hit CB-84-10 hardest, slashing DMY by 5036 kg/ha, and raised ash by 18 g/kg in M-92-9 and 9 g/kg in RGT-Planet, with no effect on others (Table 4). Despite its superior digestibility, CB-84-10 appears highly drought-sensitive, limiting its suitability for water-limited environments.

3-4 Nitrogen × Cultivar Interaction

Nitrogen increased RFV across all cultivars, with Fajr30 showing the largest gain (24 units) and CB-84-10 the smallest (10 units) (Fig. S1). This suggests that cultivars differ in their responsiveness to nitrogen fertilization, with Fajr30 being particularly efficient in converting added nitrogen into forage quality improvements.

3-5 Environment × Soil Moisture Interaction

Water deficit stress effects varied by environment. In E1, it slashed DMY by 4730 kg/ha, crude protein by 4 g/kg, and lactic acid by 10.3 g/kg DM, but raised propionic acid by 0.21 g/kg DM (Tables 5 and 10). In E2, DMY dropped by 2567 kg/ha, DIG30 by 0.02 g/kg, and lactic acid by 12 g/kg DM, with propionic acid increasing by 0.41 g/kg DM; crude protein remained unaffected (Tables 5 and 10). Water deficit stress consistently reduced lactic acid but increased propionic acid in both environments (Table 10). These consistent shifts indicate a stress-induced alteration in fermentation pathways, potentially affecting silage stability and palatability. Environment 2 (March 2018) showed stronger stress-induced changes for both acids compared to Environment 1 (October 2017) (Table 10). This emphasizes the amplifying role of warmer late-season conditions on drought impacts.

3-6 Environment × Nitrogen Interaction

Nitrogen effects differed across environments (Table S2 and Table 6). In E1, it increased DMY by 1298 kg/ha, DDM by 0.02, DIG30 by 0.04, and NEL by 0.13 MJ/kg, while cutting ADF by 29 g/kg. In E2, DMY rose by 574 kg/ha, DDM by 0.02, and DIG30 by 0.04, with ADF decreasing by 24 g/kg, but NEL showed no change (Table 6). This variability underscores the need for environment-specific nitrogen management strategies rather than uniform recommendations.

3-7 Environment × Cultivar Interaction

Environmental shifts altered ash in most cultivars except Behrokh, Fajr30, and RGT-Planet, crude protein in Nik and M-94-15, ADF in all but M-92-9 and M-93-16, DIG30 in Reyhan03, CB-84-10, M-93-16, and RGT-Planet, and DDM in all except M-92-9 and M-93-16 (Table S3). M-93-16 consistently showed the highest ash. This stability suggests strong mineral uptake capacity across environments.

Reyhan03 had peak ADF in E1, Behrokh in E2, while Reyhan03 led DIG30 in E2, and M-93-16, M-94-15, and RGT-Planet topped E1. DDM peaked in Behrokh (E1) and M-94-15 (E2). Lactic acid dropped by 5.6 and 10 g/kg DM in M-93-16 and RGT-Planet, respectively, from E1 to E2, but remained stable in Behrokh and Goharan (Fig. 2). Such rank changes reveal substantial genotype × environment interactions, reinforcing the importance of multi-environment testing for cultivar selection.

3-8 Environment × Nitrogen × Cultivar Interaction

Nitrogen reduced NDF in all cultivars across environments, with Fajr30 (66 g/kg in E1) and M-92-9 (69 g/kg in E2) showing the greatest reductions (Table 7).

3-9 Environment × Soil Moisture × Nitrogen Interaction

Water deficit stress raised SDM and NDF while lowering DIG and RFV in both environments. Nitrogen reversed these trends under control soil moisture—reducing SDM and NDF, and increasing DIG and RFV—but amplified them under water deficit (Table 8).

3-10 Environment × Soil Moisture × Cultivar Interaction

This triple interaction significantly affected SDM, TSC, NDF, pH, DIG14, and RFV (Table S4). Peak changes occurred in Fajr30 (SDM: 92 g/kg; DIG14: 0.15), M-94-15 (TSC: 5.37 mg/g DW), Behrokh (NDF: 94 g/kg; pH: 0.71; RFV: 51), while Goharan (SDM: 36 g/kg), CB-84-10 (TSC: 1.92 mg/g DW), RGT-Planet (NDF: 27 g/kg; DIG14: 0.05), Nik (pH: 0.1), and M-94-15 (RFV: 12) showed the least. Water deficit maximized SDM (except in Goharan and RGT-Planet), and low-NDF treatments yielded the highest RFV across cultivars (Table S4), under E2 conditions. These higher-order interactions collectively indicate that optimal forage quality is achievable only when moisture availability, nitrogen supply, and cultivar choice are jointly optimized.

4- Discussion

The interaction between soil moisture and nitrogen fertigation was the primary factor determining barley silage yield and quality, with opposite effects under adequate versus deficit irrigation. As expected, nitrogen application significantly increased DMY, DDM, DIG14, DIG30, and NEL at 50% depletion (Table 3; Table 4), but these improvements were consistently reduced or reversed at 85% depletion (Table 8). Mechanistically, under adequate moisture, maintained root uptake and chlorophyll stability supported coordinated protein synthesis. However, drought impaired stomatal conductance and photosynthetic nitrogen use efficiency (Bista et al., 2018; Bardehji et al., 2021). Moreover, the negative yield response to nitrogen under drought likely reflected osmotic stress, impaired nitrate assimilation, and a shift of carbon toward nitrogen metabolism instead of biomass (An et al., 2025; Wang, 2021). Consequently, this carbon-nitrogen imbalance reduced forage quality by decreasing protein and increasing fiber (Izadi et al., 2025; Liu et al., 2023). These findings confirm that nitrogen application should be matched with water availability to avoid detrimental effects.

Environmental conditions strongly modified these responses. Compared to E2, the cooler and longer growing period in E1 (autumn sowing, ~60 days longer) allowed nitrogen to improve DMY, DDM, DIG30, NEL, and crude protein while reducing ADF and NDF (Table 6), leading to superior digestibility. In contrast, the warmer E2 environment accelerated phenology and increased respiration, weakening nitrogen assimilation and yield potential. Thus, higher evaporative demand and a shorter grain-filling period in E2 likely explain the reduced nitrogen effects on quality traits. This indicates that autumn sowing can enhance nitrogen use efficiency in barley silage production.

The soil moisture × nitrogen interaction also significantly affected silage chemical composition and fermentation (Table 8; Table 9). Under control moisture, nitrogen reduced SDM, NDF, and pH while increasing crude protein, DDM, DIG14, DIG30, RFV, and NEL. Under water deficit, however, nitrogen increased SDM and NDF but reduced DIG and RFV. This reversal is attributable to drought-induced lignin deposition and reduced cell wall extensibility, which decreased substrate accessibility for microbial degradation (Choi et al., 2023). Therefore, nitrogen application under drought not only fails to improve digestibility but may actually impair it.

Across environments, water deficit consistently decreased lactic acid and increased propionic acid (Table 10), indicating a shift in fermentation metabolism. This shift likely resulted from drought-reduced soluble carbohydrates, which limited lactic acid bacteria activity, and from selection for osmotolerant propionate-producing microbes under low pH and high osmotic stress. Hence, reduced carbohydrate availability under drought constrains lactic fermentation and alters organic acid profiles, affecting silage stability (Zi et al., 2022). This highlights that moisture management is critical not only for yield but also for fermentation quality.

Cultivar-specific responses further modulated these interactions. Under control moisture, Goharan and CB-84-10 excelled in TSC and DIG14, respectively (Table 4). Under water deficit, performance differences narrowed except for RGT-Planet, which maintained partial yield stability (Table 5). This variation likely reflects differences in root hydraulic conductance, osmolyte accumulation, and nitrogen reduction capacity among cultivars (Decouard et al., 2022; Kreszies et al., 2020). The nitrogen × cultivar interaction showed that Fajr30 had the greatest nitrogen-induced RFV increase and NDF reduction, while CB-84-10 showed the smallest response (Fig. S1; Table 7). Thus, genotypic adaptation determines both nitrogen efficiency and drought resilience.

Finally, the significant triple interactions (environment × soil moisture × nitrogen/cultivar) (Tables S2, S4, S5) indicate that maximizing DMY, RFV, DIG30, and NEL requires joint optimization of irrigation, nitrogen supply, and cultivar choice. Nitrogen enhanced yield and nutritive traits only under well-watered conditions; under drought, its effectiveness declined or became detrimental (Figure 1 and Table 8). Accordingly, integrated irrigation management, adjusted nitrogen rates, and drought-tolerant cultivars are essential to maintain barley silage productivity and quality across environments. These results provide practical guidance for barley silage production in regions with contrasting water availability.

Conclusion

This study demonstrates the critical, context-dependent role of urea fertigation in barley silage production, revealing a pronounced crossover interaction with soil moisture across two distinct planting environments (fall vs. spring sowing). Water deficit stress (85% depletion) raised silage dry matter, NDF, and propionic acid but lowered digestibility, RFV, and lactic acid. Nitrogen fertigation (62.5 kg N ha^{-1}) consistently reduced NDF; under adequate moisture (50% depletion) it increased dry matter yield by 1474 kg ha^{-1} and enhanced digestibility and RFV, whereas under drought it reduced yield by 399 kg ha^{-1}. By quantifying the three-way interactions (environment × soil moisture × nitrogen) on key silage traits in a multi-environment field trial with 10 genetically diverse barley cultivars, this work provides novel, actionable insights into genotype × environment × management responses for whole-crop silage in water-limited regions. Nitrogen's contrasting effects—beneficial with water, harmful without—emphasize the need for moisture-based decision making. For farmers in semi-arid regions, we recommend applying 62.5 kg N ha^{-1} as urea fertigation when soil moisture depletion is maintained at ≤50% to maximize dry forage yield and silage quality; however, under anticipated drought conditions (≥85% depletion), nitrogen application should be reduced or withheld to prevent yield penalties and preserve fermentation profiles. These quantitative, site-specific recommendations will optimize sustainable barley silage production under variable climate scenarios.

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References

1. Albrizio, R., Todorovic, M., Matic, T., & Stellacci, A. M. (2010). Comparing the interactive effects of water and nitrogen on durum wheat and barley grown in a Mediterranean environment. *Field Crops Research,* 115(2), 179-190. doi:10.1016/j.fcr.2009.11.003
2. Al-Menaie, H., Al-Ragam, O., Al-Shatti, A., Al-Hadidi, M. A., and Babu, M. A. (2024) Effect of tillage and mulching on growth and yield performance of barley under different nitrogen and irrigation application rates. *Indian Journal of Animal Research*, **58**(8), 1320-1328. doi:10.18805/IJAR.
3. Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). *Crop evapotranspiration-Guidelines for computing crop water requirements - FAO Irrigation and drainage paper* 56.
4. An, J., Huo, H., Liu, Q. *et al.* Physiological and molecular mechanisms of nitrogen in alleviating drought stress in *Phoebe bournei*. *Sci Rep* **15**, 14684 (2025). https://doi.org/10.1038/s41598-025-99312-1
5. Anderson, V, & Schroeder, J. W. (1999). *Feeding barley to dairy cattle* (EB-72). North Dakota State University.
6. Arnetol, M., Montegrossi, G., Buccianti, A., & Gonnelli, C. (2008). Determination of organic acids in plants of *Silene paradoxa* L. by HPLC. *Journal of Agricultural and Food*

Chemistry, 56(3), 789-795. doi:10.1021/jf072203d

7. Bardehji, S., Eshghizadeh, H. R., Zahedi, M., Sabzalian, M. R., & Gheisari, M. (2021). The combined effect of nitrogen fertilizer and sowing season on response to water-limited stress in barley (*Hordeum vulgare* L.). *The Journal of Agricultural Science*, 1-19. doi: 10.1017/S0021859621000149
8. Bardehji, S., Mahlooji, M., Zare, S. et al. Comparative analysis of two-rowed and six-rowed barley genotypes: impacts of water stress and nitrogen fertilizer on yield and stress responses. CEREAL RESEARCH COMMUNICATIONS 53, 597–615 (2025). https://doi.org/10.1007/s42976-024-00555-x
9. Biancarosa, I., Espe, M., Bruckner, C. G., Heesch, S., Liland, N., Waagbø, R., Torstensen, B., &
10. Borowiec, F., Furgal, K., Kaminski, J., & Zajac, T. (1998). Nutritive value of silage made of whole barley crop harvested at various stages of maturity. *Journal of Animal Feed Science,* 7(1), 45-54.
11. Bista DR, Heckathorn SA, Jayawardena DM, Mishra S, Boldt JK. (2018). Effects of Drought on Nutrient Uptake and the Levels of Nutrient-Uptake Proteins in Roots of Drought-Sensitive and -Tolerant Grasses. Plants (Basel). 30;7(2):28. doi: 10.3390/plants7020028. PMID: 29601475; PMCID: PMC6027393.
12. Brezink, B. C., Santavec, I., & Tajnsek. A. (2002). Management system and mineral nitrogen rate impact on the barley grain composition and its nutritional value for ruminants. *Rostlinna Vyroba,* 48 (10), 463–470.
13. Carr, P. M., Horsley, R. D., & Poland. W. (2004). Barley, oat, and cereal–pea mixtures as dryland forages in northern great plains. *Agronomy Journal,* 96, 677–684. doi: 10.2134/agronj2004.0677
14. Carraro, E., & Di Iorio, A. (2022). Eligible strategies of drought response to improve drought resistance in woody crops: a mini-review. *Plant Biotechnology Reports,* 1-18.
15. Choi SJ, Lee Z, Kim S, Jeong E, Shim JS. (2023). Modulation of lignin biosynthesis for drought tolerance in plants. Front Plant Sci. 20;14:1116426. doi: 10.3389/fpls.2023.1116426. PMID: 37152118; PMCID: PMC10157170.
16. Collen, B. 2006. The barley growth guide. HGCA R&D Advisory Committee. Website: www.hgca.com, Scottish Executive Environment and Rural Affairs Department. P: 1-28.
17. Decouard B, Bailly M, Rigault M, Marmagne A, Arkoun M, Soulay F, Caïus J, Paysant-Le Roux C, Louahlia S, Jacquard C, Esmaeel Q, Chardon F, Masclaux-Daubresse C and

Dellagi A (2022) Genotypic Variation of Nitrogen Use Efficiency and Amino Acid Metabolism in Barley. Front. Plant Sci. 12:807798. doi: 10.3389/fpls.2021.807798

18. Farahani, S. M., & Chaichi, M. R. (2013). Whole forage barley crop quality as affected by different deficit irrigation and fertilizing systems. *Communications in Soil Science and Plant Analysis,* 44(20), 2961-2973. doi: 10.1080/00103624.2013.829848
19. Feiziasl, V., Jafarzadeh, J., Sadeghzadeh, B., & Shalmani, M. M. (2022). Water deficit index to evaluate water *stress status and drought tolerance of rainfed barley genotypes in cold semi-arid area of Iran. Agricultural Water Management, 262, 107395. doi: 10.1016/j.agwat.2021.107395*
20. Ferreira, G., Burch, A., Martin, L. L., Hines, S. L., Shewmaker, G. E., & Chahine, M. (2021). Effect of drought stress on in situ ruminal starch degradation kinetics of corn for silage. *Animal Feed Science and Technology,* 279, 115027.
21. Fischbeck, G. (2002). Contribution of barley to agriculture: a brief overview (pp. 1-4). GA.
22. Flaten, O., Bakken, A. K., Lindas, A., & Steinshamn, H. 2019. Forage production strategies for improved profitability in organic dairy production at high latitudes. Livestock Science, 223: 97-107. doi: org/10.1016/j.livsci.2019.03.004
23. Islam, M. R., Garcia, S. C., & Horadagoda, A. (2012). Effects of irrigation and rates and timing of nitrogen fertilizer on dry matter yield proportions of plant fractions of maize and nutritive value and in vitro gas production characteristics of whole crop maize silage. *Animal Feed Science and Technology,* 172,125-135
24. Izadi, M.H., Ashraf, M. & Emam, Y. Regulation of Physiological Attributes in Wheat Crops Under Terminal Drought Stress: A Review. Int. J. Plant Prod. 19, 781–797 (2025). https://doi.org/10.1007/s42106-025-00368-w
25. Johnson, R. R., Balwani, T. L., Johnson, L. J., McClure, K. E., & Dehority, B. A. (1966). Corn plant maturity. II. Effect on in vitro cellulose digestibility and soluble carbohydrate content. *Journal of Animal Science,* 25(3), 617-623. doi:10.2527/jas1966.253617x
26. Kreszies T, Eggels S, Kreszies V, et al. (2020). Seminal roots of wild and cultivated barley differentially respond to osmotic stress in gene expression, suberization, and hydraulic conductivity. Plant Cell Environ. 43:344–357. https://doi.org/10.1111/pce.13675

27. Liu, W., Liu, L., Yan, R., Gao, J., Wu, Sh., Liu, Y. (2023). A comprehensive meta-analysis of the impacts of intensified drought and elevated CO_2 on forage growth. Journal of Environmental Management, 327, 116885, https://doi.org/10.1016/j.jenvman.2022.116885.
28. Mahlooji, M., Seyedsharifi, R., Razmjoo, J., Sabzallian, M. R., & Sedghi, M. R. 2018. Effect of salt stress on photosynthesis and physiological parameters of three contrasting barley genotypes. Photosynthetica 56 (2): 549-556. doi: 10.1007/s11099-017-0699-y
29. Mancosu, N., Snyder, R. L., Kyriakakis, G., & Spano, D. (2015). Water scarcity and future challenges for food production. *Water*, 7(3), 975-992. doi:10.3390/w7030975
30. Nematpour, A., Eshghizadeh, H. R., & Zahedi, M. (2021). Comparing the corn, millet and sorghum as silage crops under different irrigation regime and nitrogen fertilizer levels. *International Journal of Plant Production*, 1-11.
31. Nematpour, A., Eshghizadeh, H. R., Zahedi, M., & Ghorbani, G. R. (2020). Millet forage yield and silage quality as affected by water and nitrogen application at different sowing dates. *Grass and Forage Science,* 75(2), 169-180. doi:10.1111/gfs.12475
32. Sabra DM, Reda AM, El-Shawy EA, El-Refaee YZ, Abdelraouf RE (2023). Improving barley production under deficient irrigation water and mineral fertilizers conditions. SABRAO J. Breed. Genet. 55(1): 211-229. http://doi.org/10.54910/sabrao2023.55.1.20.
33. Sun, L., Na, N., Li, X., Li, Z., Wang, C., Wu, X., Xiao, Y., Yin, G., Liu, S.; Liu, Z., Xue, Y. & Yang, F. (2021). Impact of packing density on the bacterial community, fermentation, and in vitro digestibility of whole-crop barley silage. *Agriculture*, 11(7), 672.
34. Tremblay, G. F., Bélanger, G., & Drapeau, R. (2005). Nitrogen fertilizer application and developmental stage affect silage quality of timothy (*Phleum pratense* L.). *Grass and Forage Science,* 60(4), 337-355. doi:10.1111/j.1365-2494.2005.00483.x
35. Tricase, C., Amicarelli, V., Lamonaca, E., & Leonardo Rana, R. (2018). Economic Analysis of the Barley Market and Related Uses. *Grasses as Food Feed*. doi: 10.5772/ intechopen.78967.
36. Uzun, F., Garipoğlu, A., & Ocak, N. (2017). Water use efficiency, yield, and nutritional quality of maize and sorghum cultivars as influenced by irrigation in a shallow soil. *Anadolu Tarım Bilimleri Dergisi,* 32(3), 358-366. doi: 10.7161/omuanajas.293642
37. Van Soest, P. J., Robertson, J. B., & Lewis, B. A. (1991). Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *Journal of*

Dairy Science, 74(10), 3583-3597. doi: 10.3168/jds.S0022-0302(91)78551-2

38. Vanzant, E. S., Cochran, R. C., & Titgemeyer, E. C. (1998). Standardization of in situ techniques for ruminant feedstuff evaluation. *The Journal of Animal Science,* 76, 2717-2729.
39. Vos, J., Van Der Putten, P. E. L., & Birch, C. J. (2005). Effect of nitrogen supply on leaf appearance, leaf growth, leaf nitrogen economy and photosynthetic capacity in maize (*Zea mays* L.). *Field Crops Research,* 93(1), 64-73. doi:10.1016/j.fcr.2004.09.013
40. Wallsten, J., & Hatfield, R. (2016). Cell wall chemical characteristics of whole-crop cereal silages harvested at three maturity stages. *Journal of the Science of Food and Agriculture,* 96(10), 3604-3612. doi:10.1002/jsfa.7736
41. Wang P. (2021). Friend or foe: how nitrate antagonizes ammonium toxicity. Plant Physiol. 27;186(1):210-211. doi: 10.1093/plphys/kiab095. PMID: 33686441; PMCID: PMC8154055.
42. Yolcu, H., Dasci, M, & Tan, M. (2008). Nutrient value of some Lucerne cultivars based on chemical composition for livestock. *Asian Journal of Chemistry,* 20(5), 4110.
43. Zadoks, J. C., Chang, T. T., & Konzak, C. F. (1974). A decimal code for the growth stages of cereals. *Weed Research,* 14(6), 415-421. doi:10.1111/j.1365-3180.1974.tb01084.x
44. Zi X, Wang W, Zhou S, Zhou F, Rao D, Shen P, Fang S and Wu B (2022) Prolonged drought regulates the silage quality of maize (*Zea mays* L.): Alterations in fermentation microecology. *Frontiers in Plant Science,* 13:1075407. doi: 10.3389/fpls.2022.1075407

Table 1. Physico-chemical properties of soil at the experimental site.

Depth (cm)	Soil texture	TN (%)	K (mg/kg)	P (mg/kg)	OM (%)	pH	EC (dS/m)	Clay (%)	Silt (%)	Sand (%)
0-30	CL	0.063	350	38.03	0.534	7.91	1.18	30.0	31.0	39.0
30-60	CL	0.054	359	40.03	0.904	7.75	1.22	33.3	30.0	36.7

TN, total nitrogen; K, potassium; P, phosphorus; OM, organic matter; PH, potential hydrogen; EC, electrical conductivity.

Table 2. Monthly mean minimum and maximum air temperatures, total rainfall, and evaporation during the growing period.

Environment	Month[i]	T min (℃)	T max (℃)	Rainfall (mm)	Evaporation (mm)
Environment1	October	9.9	26.9	0.000	166
	November	3.5	17.9	0.000	157
	December	-0.1	14.6	0.039	161
Environment2	January	-2.7	11.8	0.265	183
	February	4.0	16.4	0.429	209
	March	8.1	23.5	0.010	236
	April	9.5	21.6	1.149	260
	May	13.6	27.0	0.855	343
	June	20.0	35.6	0.097	351
	July	21.8	37.5	0.000	330

[i] 1th Environments (22 Oct. 2017) and 2nd Environments (4 March, 2018).

Table 3. The main effects of environments, soil moisture condition, nitrogen levels and cultivars on forage yield and silage quality traits of barley cultivars.

		At the mid-dough stage (Z85)	In silage											
Experimental Factors	Levels	DMY (kg/ha)	SDM (g/kg)	ash (g/kg)	Crude protein (g/kg DM)	TSC (mg/gDW)	ADF (g/kg)	NDF (g/kg)	DIG14 (g/kg)	DIG30 (g/kg)	pH	DDM (g/kg)	RFV	NE$_{L}$ (Mcal kg^{-1})
Environment	Environment 1	9899± 246.0^{a}	288± 2.2^{b}	113± 1.2^{b}	130.0± 0.75^{a}	6.7± 0.17^{a}	270± 2.8^{a}	434± 4.0^{a}	661± 4.2^{a}	692± 3.0^{a}	4.12± 0.037^{a}	683± 2.5^{a}	147± 1.7^{a}	6.45± 0.021^{a}
	Environment 2	8138± 151.0^{b}	314± 2.9^{a}	125± 1.3^{a}	127.0± 0.70^{b}	6.3± 0.17^{b}	275± 2.2^{a}	432± 3.1^{a}	663± 4.1^{a}	692± 4.1^{a}	4.13± 0.026^{a}	673± 2.2^{a}	146± 1.3^{a}	6.41± 0.021^{b}
Soil moisture condition^{ii}	Control	10843± 182.0^{a}	286± 2.5^{b}	117± 1.3^{b}	129.0± 0.63^{a}	5.4± 0.14^{b}	265± 2.6^{b}	420± 3.6^{b}	683± 3.4^{a}	703± 3.0^{a}	4.07± 0.035^{b}	680± 2.2^{a}	152± 1.5^{a}	6.62± 0.017^{a}
	Stress	7194± 88.4^{b}	317± 2.2^{a}	121± 1.4^{a}	128.0± 0.82^{b}	7.6± 0.14^{a}	281± 2.2^{a}	446± 3.2^{a}	643± 3.0^{b}	675± 3.5^{b}	4.18± 0.028^{a}	673± 2.0^{b}	141± 1.4^{b}	6.33± 0.017^{b}
Nitrogen^{iii}	N0	8550± 188.0^{b}	307± 2.7^{a}	112± 1.2^{b}	123.0± 0.66^{b}	7.1± 0.17^{a}	286± 2.4^{a}	452± 3.4^{a}	642± 3.4^{b}	671± 3.4^{b}	4.18± 0.032^{a}	676± 2.4^{b}	138± 1.4^{b}	6.41± 0.021^{b}
	N1	9487± 239.0^{a}	295± 2.8^{b}	126± 1.2^{a}	134.0± 0.44^{a}	5.9± 0.16^{b}	259± 2.1^{b}	414± 2.8^{b}	673± 4.0^{a}	712± 3.0^{a}	4.06± 0.031^{b}	695± 2.0^{a}	155± 1.3^{a}	6.49± 0.025^{a}
cultivars	Goharan	9494± 508.0^{ab}	309± 7.6^{bc}	116± 3.8^{de}	130± 1.2^{a}	8.3± 0.39^{a}	276± 4.8^{bc}	430± 5.2^{c}	642± 6.2^{ef}	712± 6.2^{b}	4.29± 0.060^{b}	672± 4.2^{cd}	146± 2.5^{c}	6.45± 0.046^{a}
	Behrokh	8720± 419.0^{c}	300± 3.9^{de}	117± 2.0^{c-e}	129± 1.8^{ab}	5.7± 0.35^{e}	267± 9.2^{cd}	417± 9.5^{d}	673± 8.0^{c}	670± 6.4^{d}	3.94± 0.058^{de}	685± 7.1^{bc}	154± 4.7^{b}	6.45± 0.063^{a}
	Nik	8997± 539.0^{bc}	304± 6.9^{cd}	117± 2.7^{b-e}	130± 1.9^{a}	6.1± 0.29^{c-e}	269± 4.2^{cd}	444± 7.8^{b}	660± 7.2^{d}	683± 5.3^{c}	3.91± 0.062^{e}	674± 3.4^{d}	142± 2.9^{d}	6.41± 0.050^{a}
	Fajr30	9575± 484.0^{a}	312± 5.5^{b}	122± 1.9^{bc}	128± 1.9^{ab}	5.8± 0.34^{e}	270± 5.3^{cd}	457± 7.3^{a}	683± 12.0^{b}	701± 5.3^{b}	4.12± 0.052^{c}	684± 4.0^{bc}	139± 2.9^{d}	6.45± 0.050^{a}
	Reyhan03	8743± 302.0^{c}	299± 5.9^{d-f}	115± 2.7^{de}	130± 1.4^{ab}	6.4± 0.30^{cd}	295± 5.5^{a}	464± 6.8^{a}	673± 7.2^{c}	705± 9.3^{b}	4.20± 0.067^{bc}	660± 4.1^{e}	133± 2.7^{e}	6.37± 0.050^{a}
	CB-84-10	9664± 597.0^{a}	294± 4.2^{e-g}	122± 2.4^{b}	126± 1.5^{b}	5.7± 0.23^{e}	257± 4.1^{f}	409± 7.3^{d}	634± 7.1^{a}	66.3± 8.0^{d}	3.82± 0.076^{e}	692± 3.3^{a}	158± 3.2^{a}	6.49± 0.046^{a}
	M-92-9	9446± 465.0^{ab}	281± 7.4^{h}	119± 3.7^{b-d}	127± 1.6^{ab}	6.5± 0.34^{c}	289± 3.5^{a}	460± 7.3^{a}	655± 7.0^{de}	681± 5.1^{c}	4.49± 0.047^{a}	663± 3.0^{e}	135± 2.6^{e}	6.37± 0.050^{a}
	M-93-16	8529± 394.0^{cd}	331± 5.1^{a}	136± 2.6^{a}	129± 1.8^{ab}	6.0± 0.39^{de}	289± 2.8^{a}	412± 5.4^{d}	642± 6.1^{f}	683± 10.1^{c}	4.10± 0.075^{c}	693± 2.4^{a}	156± 2.4^{a}	6.54± 0.046^{a}
	M-94-15	8994± 460.0^{bc}	289± 4.6^{g}	115± 2.5^{de}	128± 1.6^{ab}	7.1± 0.44^{b}	265± 4.5^{de}	427± 4.4^{c}	653± 8.4^{de}	724± 5.4^{a}	4.23± 0.050^{bc}	680± 3.2^{b}	149± 2.1^{c}	6.49± 0.050^{a}
	RGT-Planet	8064± 472.0^{d}	292± 5.0^{fg}	112± 2.6^{e}	129± 1.5^{ab}	7.6± 0.32^{b}	269± 4.5^{cd}	409± 5.8^{d}	631± 6.5^{f}	711± 6.3^{ab}	4.10± 0.049^{cd}	682± 4.1^{bc}	155± 2.7^{ab}	6.45± 0.046^{a}

DMY, dry matter yield; SDM, silage dry mater content; TSC, total soluble carbohydrate; ADF, acid detergent fiber; NDF, neutral detergent fiber; DIG14, digestibility after 14 hours; DIG30, digestibility after 30 hours; DDM, digestible dry matter; RFV, relative feed value; NEL, net energy for lactation. ^{i}Environment 1 (22 Oct. 2017) and Environment 2 (4 March, 2018), ^{ii}Irrigation (control, 55% MAD and stress, 85% MAD), ^{iii}Nitrogen (N0, 0 kg/ha and N1, 62.5 kg/ha). In each column and within each factor, numbers followed by the same letter are not significantly different (*P*<0.05).

Table 4. The interaction effects of soil moisture conditions and cultivars on DMY and ash in barley.

Barley cultivars	At the mid-dough stage (Z85)		In silage	
	DMY (kg/ha)		Ash (g/kg)	
	Control[i]	Stress	Control	Stress
Goharan	11684 ± 456.0^{ab}	7304 ± 216.0^{g}	117 ± 5.1^{ef}	$114\pm6.0^{e-g}$
Behrokh	$10348\pm483.0^{d-f}$	7091 ± 227.0^{g}	$113\pm2.9^{e-g}$	120 ± 2.6^{de}
Nik	10863 ± 737.0^{cd}	7132 ± 304.0^{g}	128 ± 3.3^{de}	115 ± 4.6^{ef}
Fajr30	11589 ± 476.0^{ab}	7561 ± 242.0^{g}	119 ± 2.9^{de}	125 ± 2.6^{cd}
Reyhan03	10117 ± 572.0^{ef}	7288 ± 356.0^{g}	$115\pm3.6^{e-g}$	116 ± 4.3^{ef}
CB-84-10	12182 ± 351.0^{a}	7146 ± 313.0^{g}	$118\pm3.\ 6^{de}$	125 ± 3.2^{cd}
M-92-9	11226 ± 538.0^{bc}	7666 ± 281.0^{g}	110 ± 4.2^{fg}	128 ± 5.2^{bc}
M-93-16	9863 ± 518.0^{f}	7196 ± 295.0^{g}	135 ± 3.6^{ab}	136 ± 4.0^{a}
M-94-15	$10706\pm586.0^{c-e}$	7281 ± 214.0^{g}	$115\pm3.6^{e-g}$	115 ± 3.8^{ef}
RGT-Planet	9851 ± 580.0^{f}	6278 ± 233.0^{h}	107 ± 3.3^{g}	116 ± 4.0^{ef}

DMY, dry matter yield; [i] Soil moisture conditions (control, 55% MAD and stress, 85% MAD). In each trait, numbers followed by the same letter are not significantly different (*P*<0.05).

Table 5. The interaction effects of environments and soil moisture conditions on DMY, CP and DIG30 in barley cultivars.

Traits		Environment 1[i]		Environment 2	
		Control[ii]	Stress	Control	Stress
DMY (kg/ha)	At the mid-dough stage (Z85)	12264 ± 194.0^{a}	7534 ± 140.0^{c}	9422 ± 169.0^{b}	6855 ± 90.0^{d}
Crude protein (g/kg DM)	In silage	132.0 ± 0.94^{a}	128 ± 1.1^{b}	128.0 ± 0.73^{b}	127 ± 1.2^{b}
DIG30 (g/kg)	In silage	712 ± 4.2^{a}	673 ± 4.0^{b}	70.4 ± 5.1^{a}	684 ± 5.1^{b}

DMY, dry natter yield; DIG30, digestibility after 30 hours; [I] Environment 1 (22 Oct. 2017) and Environment 2 (4 March, 2018). [ii] Soil moisture conditions (control, 55% MAD and stress, 85% MAD). In each trait, numbers followed by the same letter are not significantly different (*P*<0.05).

Table 6. The interaction effects of environments and nitrogen levels on DMY, DIG30, DDM and NE_L of silage in barley cultivars.

Traits		Environment 1[i]		Environment 2	
		N0[ii]	N1	N0	N1
DMY (kg/ha)	At the mid-dough stage (Z85)	9250 ± 309.0^{b}	10548 ± 370.0^{a}	7851 ± 179.0^{d}	8425 ± 240.0^{c}
ADF (g/kg)	In silage	285 ± 3.8^{a}	256 ± 3.2^{c}	287 ± 2.9^{a}	263 ± 2.6^{b}
DDM (g/kg)	In silage	671 ± 3.21^{c}	692 ± 2.11^{a}	660 ± 2.14^{c}	683 ± 2.33^{b}
DIG30 (g/kg)	In silage	682 ± 4.12^{b}	724 ± 4.25^{a}	672 ± 4.32^{b}	715 ± 4.11^{a}
NE_L (Mcal kg^{-1})	In silage	6.41 ± 0.029^{b}	6.54 ± 0.034^{a}	6.41 ± 0.029^{b}	6.49 ± 0.034^{ab}

DMY, dry matter yield; ADF, acid detergent fiber; DDM, digestible dry matter; DIG30, digestibility after 30 hours; NE_L, net energy for lactation. [I] Environment 1 (22 Oct. 2017) and Environment 2 (4 March, 2018), [ii] Nitrogen fertilizer (N0, 0 kg/ha and N1, 62.5 kg/ha). In each trait, numbers followed by the same letter are not significantly different (*P*<0.05).

Table 7. The interaction effects of environments, nitrogen levels and cultivars on NDF of barley silage.

	Environment 1^{i}		Environment 2	
cultivars	N0^{ii}	N1	N0	N1
Goharan	452±6.6^{d-f}	429±5. 8^{h-k}	437±11.6^{f-h}	402±7.2^{m-o}
Behrokh	393±2.7^{o-q}	373±7.1^{r}	484±13.4^{b}	416±9.2^{j-m}
Nik	489±5.8^{ab}	437±2.5^{f-i}	449±11.1^{d-g}	402±5. 8^{m-o}
Fajr30	504±4.9^{a}	438±9.4^{e-h}	464±7.4^{cd}	421±9. 7^{i-l}
Reyhan03	493±6.8^{ab}	478±7.9^{bc}	462±9.5^{d}	424±12.5^{h-i}
CB-84-10	378±4.8^{qr}	379±7.4^{qr}	454±7.0^{de}	424±8.2^{h-l}
M-92-9	492±8.7^{ab}	448±10.2^{d-g}	485±6.8^{b}	416±6.4^{k-m}
M-93-16	432±5.1^{h-j}	397±6.9^{n-p}	427±13.6^{h-l}	391±7.1^{o-q}
M-94-15	433±6.6^{g-i}	417±7.5^{j-m}	448±73.2^{d-g}	412±7. 4^{l-n}
RGT-Planet	426±8.4^{h-l}	387±6.8^{o-r}	438±7.4^{f-h}	385±5.1^{p-r}

^{I} Environment 1 (22 Oct. 2017) and Environment 2 (4 March, 2018), ^{ii} Nitrogen fertilizer (N0, 0 kg/ha and N1, 62.5 kg/ha). Numbers followed by the same letter are not significantly different (*P*<0.05).

Table 8. The interaction effects of environments, irrigation regimes and nitrogen levels on SDM, NDF, DIG14 and RFV in barley silage.

Environment	Soil moisture condition^{ii}	Nitrogen^{iii}	SDM (g/kg)	NDF (g/kg)	DIG14 (g/kg)	RFV
Environment 1	Control	N0	278±3.0e	441±4.3c	663±7.21b	144±1.4c
		N1	268±2.6f	404±3.9f	701±5.11a	161±1.6a
	Stress	N0	291±3.3d	432±4.0d	662±4.22b	149±2.0b
		N1	314±3.9b	458±5.1b	624±9.15d	136±1.2d
Environment 2	Control	N0	302±6.0c	438±6.0cd	664±8.41b	143±2.3c
		N1	294±3.2d	396±4.4g	703±10.3a	162±2.8a
	Stress	N0	328±4.3a	422±3.8e	643±11.4c	150±1.3b
		N1	334±4.1a	472±5.0a	624±4.22d	131±2.2e

SDM, silage dry matter content; NDF, neutral detergent fiber; DIG14, digestibility after 14 hours; RFV, relative feed value. ^{I} Environment 1 (22 Oct. 2017) and Environment 2(4 March, 2018), ^{ii}Soil moisture condition (control, 55% MAD and stress, 85% MAD); ^{iii}Nitrogen (N0, 0 kg/ha and N1, 62.5 kg/ha). In each column and within each factor, numbers followed by the same letter are not significantly different (*P*<0.05).

Table 9. The main effects of environments, irrigation regimes and cultivars on acetic, lactic, propionic and butyricacid content of barley silage.

Experimental Factors	Levels	In silage			
		Acetic	Lactic	Propionic	Butyric
		(g/kg DM)			
Environments	Environment 1	14.5±0.41^{a}	40±1.4^{a}	1.77±0.045^{b}	0.11±0.006^{a}
	Environment 2	11.9±0.32^{b}	36±1.5^{b}	1.96±0.051^{a}	0.10±0.006^{b}
Soil moisture condition^{ii}	Control	14.3±0.43^{a}	43.5±0.85^{a}	1.72±0.039^{b}	0.13±0.003^{a}
	Stress	12.0±0.36^{b}	33±1.1^{b}	2.01±0.045^{a}	0.08±0.004^{b}
Cultivar	Behrokh	13.4±0.53^{ab}	38±1.6^{b}	1.78±0.058^{bc}	0.10±0.007^{b}
	Goharan	13.1±0.74^{ab}	41±1.4^{a}	1.89±0.068^{b}	0.12±0.008^{a}
	M-93-16	12.2±0.55^{b}	33±2.3^{c}	1.71±0.063^{c}	0.09±0.008^{c}
	RGT-Planet	13.9±0.65^{a}	40±2.3^{ab}	2.09±0.048^{a}	0.11±0.009^{a}

^{I} Environment 1 (22 Oct. 2017) and Environment 2 (4 March, 2018), ^{ii}Soil moisture condition (control, 55% MAD and stress, 85% MAD). In each trait, numbers followed by the same letter are not significantly different (*P*<0.05).

Table 10. The interaction effects of environments and soil moisture condition on lactic and propionic acid content in barley silage.

Traits	Environment 1 [i]		Environment 2	
	Control[ii]	Stress	Control	Stress
Lactic (g/kg DM)	45.4±1.3[a]	35.1±1.4[c]	42.0±0.94[b]	30±1.5[d]
Propionic (g/kg DM)	1.67±0.054[c]	1.88±0.055[b]	1.73±0.051[bc]	2.14±0.048[a]

[I] Environment 1 (22 Oct. 2017) and Environment 2 (4 March, 2018), [ii] Soil moisture condition (control, 55% MAD and stress, 85% MAD). In each trait, numbers followed by the same letter are not significantly different (P< 0.05).

عملکرد علوفه خشک و کیفیت سیلاژ کامل جو (*Hordeum vulgare* L.) ارقام تحت تأثیر برهمکنش خشکی و کودآبیاری نیتروژن

سیاوش برده جی، حمیدرضا عشقی زاده، مرتضی زاهدی، و مهرداد محلوجی

چکیده

سیلاژ جو سنگ بنای خوراک دام پایدار است، با این حال تولید آن با فشار فزاینده‌ای از کمبود آب و شرایط رشد متغیر مواجه است. هدف از این مطالعه بررسی چگونگی تأثیر شرایط رطوبت خاک (50٪ و 85٪ تخلیه آب خاک) و کوددهی نیتروژن (N) (0 و 62.5 کیلوگرم نیتروژن در هکتار به صورت اوره، 46-0-0) بر عملکرد علوفه خشک (DFY) و کیفیت سیلاژ 10 رقم جو در دو محیط کاشت مجزا (E1: 22 اکتبر 2017؛ E2: 4 مارس 2018) بود. نتایج ما که در آزمایش‌های میدانی در سال‌های 2017 و 2018 انجام شد، یافته اصلی یک دوگانگی قابل توجه را نشان می‌دهد: کوددهی نیتروژن، عملکرد ماده خشک (DMY) را در شرایط آبیاری مناسب 1474 کیلوگرم در هکتار افزایش داد، اما در شرایط تنش خشکی آن را 399 کیلوگرم در هکتار کاهش داد. این تعامل همچنین بر کیفیت سیلو تأثیر گذاشت، به طوری که تنش خشکی باعث افزایش ماده خشک سیلو(SDM) ، فیبر شوینده خنثی (NDF) و اسید پروپیونیک در حالی که قابلیت هضم (DIG) ، ارزش نسبی خوراک (RFV) و محتوای اسید لاکتیک را کاهش داد، در حالی که کودآبیاری با نیتروژن، NDF را کاهش داد و در شرایط رطوبت کافی، DIG و RFV را افزایش داد. مفهوم کاربردی این است که این بینش‌ها، استراتژی‌های مدیریت بهینه نیتروژن را برای افزایش عملکرد و کیفیت سیلوی جو در مناطق کم‌آب امکان‌پذیر می‌سازد.