Effects of saline and non-saline irrigation water on yield and water productivity of autumn cereal forages in semi-arid regions

Seyed Hassan Mousavi Fazl

Agricultural Engineering Research Department, Agricultural and Natural Resources Research and Education Center of Semnan Province (Shahrood), AREEO, Shahrood, Iran. (h.mousavifazl@areeo.ac.ir),

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Abstract

Forage production is essential for Iran's livestock industry. Due to climate change, water scarcity, hot and dry conditions, increased evapotranspiration, and deteriorating water and soil quality, there is a need to utilize forages adapted to drought and salinity. Producing fresh forage outside summer also alleviates water pressure and reduces silage costs. This study investigated the feasibility of producing autumn-sown green forages (wheat, barley, triticale) under saline irrigation and determined their water productivity. A field experiment was conducted in two regions of Semnan province with contrasting water qualities: Farm No. 1 in Bastam (non-saline water, EC = 1.151 dS/m) and Farm No. 2 in Tal (saline water, EC = 12.65 dS/m). At each farm, nine treatments (three varieties each of wheat, barley, and triticale) were arranged in a randomized complete block design with three replications. Soil physicochemical properties and irrigation water quality were analyzed prior to planting. Planting occurred in late November, with harvest in late May at the dough stage. Results showed that plant height, spike length, fresh forage yield, water productivity, and crude protein percentage were significantly affected by irrigation water quality. Salinity stress in Tal reduced these parameters by 40%, 19%, 71%, 78%, and 26%, respectively. Triticale produced the maximum forage yield, followed by wheat and barley. Fresh forage yield was 60.3 t/ha in Bastam (non-saline) versus 17.4 t/ha in Tal (saline). Water productivity was 10.7 kg/m³ in Bastam and 2.34 kg/m³ in Tal. Mean crude protein was 10.17% in Bastam and 7.49% in Tal. Based on quantitative parameters, growth characteristics, and forage quality, the cultivation priority under both conditions was triticale, then wheat, then barley. Specifically, triticale cultivars Paj, Hashemi, and Sanabad, and the wheat cultivar Narin showed higher priority than other forages under both saline and non-saline conditions.

Introduction

Semnan Province is located between the central desert of Iran and the southern slopes of the Alborz Mountain Range, resulting in diverse climatic parameters (Naseri et al., 2023). The long-term average rainfall in Semnan Province is 145 mm, while in Shahrood it reaches 169 mm. Specifically, the seasonal rainfall distribution in Shahrood is 25 mm, 48 mm, and 56 mm for autumn, winter, and spring, respectively (Iran Meteorological Organization, 2024). More than 80% of the province's agricultural water is supplied from groundwater sources. However, the quality of groundwater in large parts of the province (including Ivanaki, Garmsar, Semnan, Damghan, and parts of Shahrood) is undesirable and exhibits high salinity (classified as C3 and C4). The average electrical conductivity (EC) of water resources in these vast areas exceeds 3.5 dS/m, with irrigation water salinity in some regions reaching over 12 dS/m (Semnan Province Agricultural Productivity Report, 2017).

Autumn-sown cereal forages, including barley, wheat, triticale, and oats, are widely cultivated in semi-arid regions due to their adaptability to low temperatures and moderate tolerance to salinity. Among these species, barley is generally considered more salt-tolerant than wheat, while triticale exhibits intermediate tolerance depending on

the genotype (Munns and Gilliham, 2015). From an agronomic perspective, autumn-sown cereal forages are less expensive than summer crops due to their reliance on rainfall, lower evapotranspiration rates, and no need for silage preservation. This shift in production timing contributes to improved water productivity and alleviates pressure on freshwater resources.

Barley is a prominent winter grain used for autumn forage production. Reported fresh forage yields for barley varieties range from 30 to 50 tons per hectare, with dry forage yields between 7 to 12 tons. Water consumption for barley autumn forage is reported to be approximately 3,000 to 4,000 m^3/ha under pressurized irrigation and 4,000 to 5,000 m^3/ha under surface irrigation methods (Azerbaijani et al., 2014). Regarding forage quality, triticale is nutritionally inferior to barley; therefore, it is often recommended to harvest triticale earlier than other cereals for optimal silage production (Torabi and Salemi, 2019).

While studies focusing exclusively on the effects of salinity on triticale forage production remain limited, research addressing soil salinity and nutritional management has demonstrated that green biomass production, water content, and nutrient composition are influenced by salinity stress. In areas with varying salinity levels, the application of organic amendments, such as humic and fulvic acids, has been shown to partially alleviate the adverse effects of salinity. These practices increase the production of fresh, protein-rich forage and enhance protein and carbohydrate contents under saline conditions (Mosaad et al., 2024). Physiological adaptations, such as osmotic adjustment, play a crucial role in maintaining plant productivity under combined salinity and water stress conditions. However, species and genotype-specific differences in tolerance thresholds necessitate comparative evaluation under local agro-climatic conditions.

Water productivity (WP), commonly defined as the ratio of biomass yield to the volume of water consumed (kg m^{-3}), has become a key indicator for evaluating irrigation efficiency under scarcity conditions (Zhang et al., 2018). Enhancing WP under saline irrigation requires integrated management practices, including appropriate crop selection, optimized irrigation scheduling, and salinity control strategies. According to the Food and Agriculture Organization (FAO, 2022), improving water productivity in salt-affected and water-scarce regions is essential for achieving sustainable agricultural intensification and ensuring feed security in livestock-dependent systems. Therefore, assessing the effects of saline and non-saline irrigation water on yield and water productivity of autumn cereal forages is essential for developing adaptive irrigation strategies tailored to semi-arid environments (Blum, 2017).

This study was conducted to investigate the potential for producing autumn green forage (wheat, barley, and triticale) under saline water conditions, with the aim of utilizing rainfall (green water), optimizing water consumption, and ensuring the continuity of fresh forage supply.

Materials and Methods

This study was conducted in two regions located 40 km apart, featuring similar climatic conditions but differing in irrigation water quality. Region 1 was situated at the Agricultural Research and Education Center of Semnan Province (Shahrood), located at kilometer 3 of the Shahrood-Bastam road, with an average annual rainfall of 175 mm and a long-term mean annual temperature of 18.4°C. Region 2 consisted of the lands of a leading farmer in the south of Shahrood (Tal - Yunus Abad), located at kilometer 30 of the Shahrood-Torud road, with an average annual rainfall of 135 mm and a long-term mean annual temperature of 19.7°C. According to long-term statistics, the dry period in both regions extends from mid-May to mid-November. Based on the Ambroge climate classification, the climate of both regions is categorized as hot and dry.

Water Quality

In order to determine the quality of irrigation water, a sample of water used in 2 farms No. 1 and 2 was prepared and tested. The results of the qualitative analysis of the tested waters are presented in Table (1).

Physical and Chemical Properties of Soil

In order to determine the physical and chemical properties of the soil, soilsamples from both fields (depths of 0-30 and 30-60 cm) were prepared and transferred to the laboratory. After drying the samples and crushing them by passing them through a 2 mm sieve, soil texture was determined using the hydrometric method, soil apparent specific gravity by the paraffin method (intact samples), and moisture content at field capacity and wilting point were determined using pressure plates at 0.3 and 15 bar suction. Using saturated mud prepared from the soil sample, its pH was measured using a pH meter and soil electrical conductivity was measured using a conductivity meter. Soil phosphorus was determined using a spectrophotometer, total soil nitrogen by the Kjeldahl method, and potassium was determined using the ammonium acetate method using a Genovese flame photometer. Table (2) shows the physicochemical properties of the soil of the two farms.

Table 1- Results of water quality analysis of farms

Location	EC (dS/m)	pH	Anions (meq/lit)			Cations (meq/lit)			SAR*
			$HCO_3^- + CO_3^{2-}$	$SO4^{2-}$	Cl^-	K^+	Na^+	$Ca^{2+} + Mg^{2+}$	
1	1.151	8.1	2.98	0.92	5.2	-	3.5	5.6	2.1
2	12.650	7.24	2.26	0.92	87	-	91.7	45.6	19.2

Location 1: Lands of Semnan Agricultural Research, Education and Natural Resources Center and location 2: Lands of Tal in the south of Shahrood
* Sodium adsorption ratio

Table 2- Physical-chemical properties of soil in the regions

parameters	Location 1		Location 2	
	Soil depth (cm)		Soil depth (cm)	
	0-30	30-60	0-30	30-60
Soil texture	Loam	Loam	Loam	Loam
Sand (%)	45	45	47	48
Silt (%)	32	34	39	38
Clay (%)	23	21	14	14
Apparent specific gravity (gr/cm^3)	1.46	1.59	1.48	1.47
Moisture content at field capacity (%)	20.7	19.7	20.2	19.8
Moisture content at wilting point (%)	9.5	9	9.4	9
Soil acidity (pH)	7.9	7.8	7.8	7.9
EC of saturated soil extract (dS/m)	1.4	1.3	23.3	22.6
Nutrients				
Absorbable potassium (ppm)	150	150	246	246
Absorbable phosphorus (ppm)	16	12	11.6	12
Total nitrogen (%)	0.05	0.05	0.06	0.06

Research Method

To investigate the production capacity and determine the water productivity in the production of autumn green forage of cereals (wheat, barley and triticale varieties), a field study was conducted from October 2024 in two independent farms with different qualities of irrigation water (Bastam region and the outskirts of Shahrood city). Farm No. 1 in the Bastam region (the lands of Shahrood Agricultural Research and Education Center) was used with irrigation water without salinity restrictions (EC = 1.151 dS/m) with a tape drip irrigation system (tape), farm No. 2 in the outskirts of Shahrood (Local farmer's farm) was used with high salinity of irrigation water (EC = 12.650 dS/m) and with the border (strip) irrigation method (traditional irrigation).

In this study, to examine the effects of irrigation water quality on autumn and winter cereal forage, two water sources with contrasting salinities were selected: non-saline water (EC = 1.150 dS/m) as the control and highly saline water (EC= 12.650 dS/m) representing the region's dominant stress conditions. Two locations were included to account for differences in soil properties and local climate, allowing a comprehensive assessment of both water quality and environmental variability on forage yield and water productivity under semi-arid conditions. Two irrigation methods were employed:drip irrigation in the Bastam region and border (strip) irrigation in the Tal region. The choice of irrigation method was based on soil characteristics, technical requirements, and typical regional practices. In Bastam, where non-saline water was available, the sandy, gravelly soil with high permeability made surface irrigation inefficient due to high water losses; therefore, drip irrigation was selected as the most suitable technical option. In Tal Shahrood, where highly saline water was used, seed germination and early plant establishment were limited under methods other than border irrigation. Consequently, border irrigation (traditional) was implemented as the most appropriate method compatible with the salinity conditions. Overall, the experimental design was structured to compare two management systems suited to the actual conditions of each region, allowing the results to be interpreted in the context of practical exploitation scenarios.

In each field, 9 treatments were compared in a randomized complete block design with three replications (total 27 treatments). The experimental treatments included: 1- Paj triticale 2- Hashemi triticale 3- Sanabad triticale 4- Mihan wheat 5- Zarrineh wheat 6- Narin wheat 7- Bahman barley 8- Azaran barley 9- Golshan barley. Each experimental plot (in each field) consisted of 6 rows with a row spacing of 50 cm and a planting line length of 8 m. The crop was planted manually in late November. The seed consumption rate for barley varieties was 150, for wheat and triticale 200 kg/ha. As mentioned, these treatments were implemented in two different qualities of irrigation water (two separate fields, but under the same climatic conditions).

To determine the physicochemical properties of the soil of both farms before planting, samples were prepared from three points of each farm (depth 0 to 30 cm) and the related parameters such as soil texture, percentage of sand, clay and silt, electrical conductivity, nitrogen, organic matter, acidity, sodium, calcium, carbonates and bicarbonates were measured in the laboratory.

To determine the quality characteristics of the irrigation water of the two farms, a water sample was prepared from each of the water sources of the relevant fields and transferred to the laboratory and the chemical properties of the water samples (including electrical conductivity, acidity, anions and cations and SAR) were determined. To periodically examine the quality of the water of the wells used in both farms during the growing season (early autumn, winter and spring), samples were prepared and the chemical properties of the samples were determined so that they could be used in interpreting the results of the research data.

Irrigation water for treatments was calculated based on meteorological data from the nearest local meteorological station using the Penman-Monteith method and was provided to the treatments with an irrigation interval of 5 and 7 days (Bastam and Tal regions, respectively). The volume of irrigation water during the irrigation season

in each field was measured using a Parshall Flume (in border irrigation) and a volumetric meter in the drip method. During the growing season, the required chemical fertilizers were determined based on soil tests and provided to the plants in different treatments. Harvesting was done at the soft dough stage (late May), from an area of 6 square meters of each plot, and green forage was weighed and the yield of the crop was determined in each treatment. Before harvesting, plant growth characteristics such as plant height, panicle length and some other parameters were measured.

Water Use Productivity Index

One of the agricultural water productivity indices is the physical agricultural water productivity index, which is obtained from the ratio of crop yield (kg/ha) to the volume of irrigation water and effective rainfall (m^3/ha). The water productivity index in crop production was calculated using the equation (1) :

$$WP=Y/(I+P) \quad (1)$$

where:
WP= Physical water productivity in crop production (kg/m^3 of applied water)
Y= Crop yield (kg/ha)
I= Volume of irrigation water during the season (m^3/ha)
P= Volume of water resulting from effective rainfall during the season (m^3/ha)
In addition to physical productivity, economic productivity was also examined for different treatments.

Data Analysis

After data collection, variance analysis of the results was performed in each farm and the means were examined by Duncan's test and the best treatment was determined. Considering that the experiment was conducted in two regions with different irrigation water quality, spatial composite analysis of the data was also performed. Then, the best treatment was determined by comparing the means. SAS software was used to analyze the variance of the data and compare the means, and Excel software was used to draw graphs.

Results and Discussion

Data were statistically analyzed using SAS software. Table (3) presents the results of the combined analysis of variance for the studied parameters in the two regions.

Table 3- Composite analysis of variance of the studied traits of the treatments in the two regions

Sources of change	Mean squares				
	Plant height	Spike length	Wet weight of forage	Dry weight of forage	Water productivity
Location	18021.9**	43.2**	24897.1**	9358.1**	947.4**
Error	226.2	0.25	25.4	5.3	0.21
Treatment	1132.3**	27.3**	278.9**	26.8*	7.6**
Treatment in the location	78.3*	0.45^{ns}	251.5**	28.2*	6.9**
Error	26.1	0.45	22.6	10.2	0.69
Coefficient of variation (%)	6.9	8	12.3	14.7	12.7

Ns, *, ** is not significant, significant at the 5 and 1 percent levels, respectively

Effect of irrigation water salinity on plant height

Statistical analysis revealed a significant difference ($p < 0.01$) in plant height between the two regions (Table 3). The Bastam

region, with an average plant height of 91.5 cm, ranked in the superior statistical group, while the Tal region, with an average height of 54.9 cm, fell into the lower statistical group. Salinity stress reduced plant height by 40% (Fig. 1). Fig. (2) illustrates a comparison of the growth status of forage crops in the two regions (irrigated with saline and non-saline water). The significant reduction (40%) in plant height under saline irrigation can be attributed to osmotic stress and ion toxicity in the root zone. Increased salinity lowers soil water potential, restricts water uptake, and reduces cell elongation, ultimately limiting stem growth. Similar reductions in the plant height of cereal crops under saline conditions have been reported by Munns and Gilliham (2015), who emphasized that salinity primarily inhibits shoot growth through osmotic effects and ionic imbalance. Therefore, the lower plant height observed in the saline region is consistent with the established physiological responses of cereals to salt stress.

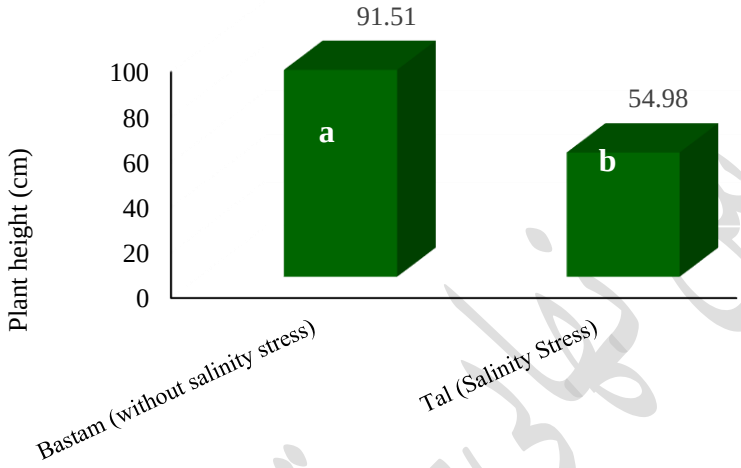


Fig- 1- Average plant height



a- Tal (salinity stress) **b- Bastam (without salinity stress)**

Fig. 2- Comparison of forage type, cultivars and growth characteristics in saline and non-saline water

Fig. (3) illustrates the percentage of plant height reduction in the experimental treatments across the two regions. Among the individual cultivars, Narin wheat exhibited

the lowest reduction (29.5%), while Bahman barley showed the highest reduction (62.2%). However, when comparing the crop species as a whole, the average percentage of plant height reduction with increasing salinity was 10.53%, 23.35%, and 69.33% for barley, wheat, and triticale, respectively. Therefore, under increasing salinity stress, triticale exhibited the highest susceptibility to height reduction, followed by wheat and barley (Fig. 3).

The composite analysis of plant height revealed a highly significant difference ($p < 0.01$) between the experimental treatments for this trait (Table 3). The triticale treatments Hashemi, Paj, and Sanabad exhibited the greatest plant height among the treatments, ranking in the superior statistical group, respectively. Wheat cultivars Narin, Zarrineh, and Mihan fell into the next statistical group, while the barley cultivars Azaran, Golshan, and Bahman were placed in the lowest statistical group (Fig. 4).

Analysis of plant height across different crops in the experimental areas indicated that the average height for triticale, wheat, and barley was 89.4, 69.6, and 60.7 cm, respectively. In other words, triticale produced the tallest plants. Triticale plants were 28.4% and 47.3% taller than wheat and barley, respectively. Furthermore, wheat height was 14.7% greater than that of barley (Fig. 5).

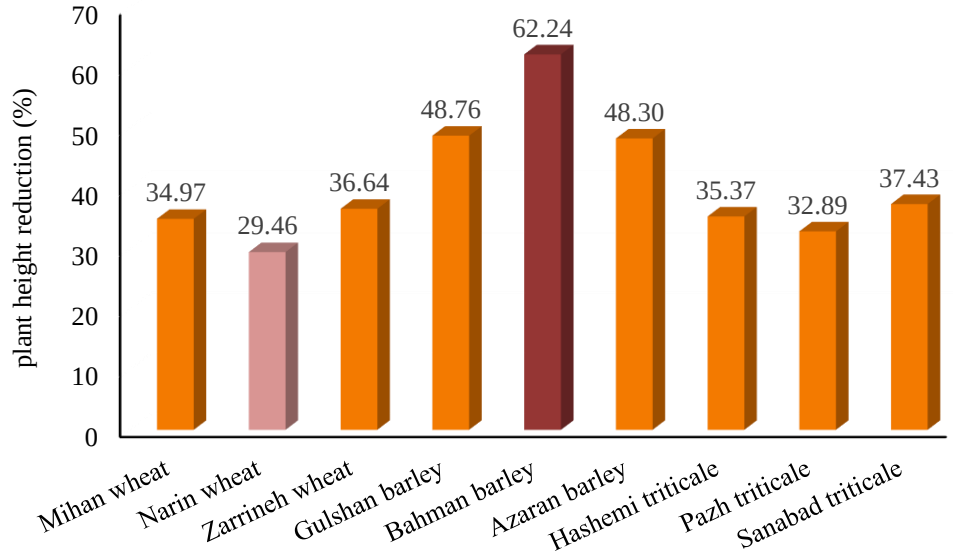


Fig. 3- Average percentage of plant height reduction in experimental treatments in the regions

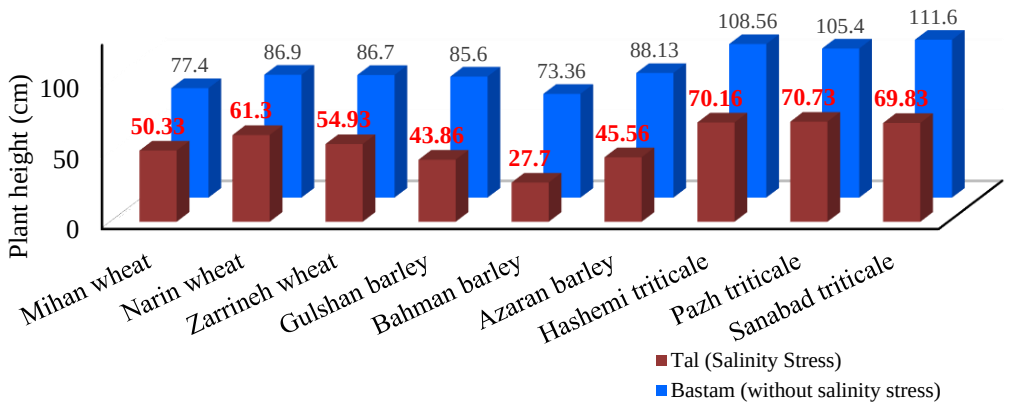


Fig. 4- Average plant height of experimental treatments in regions

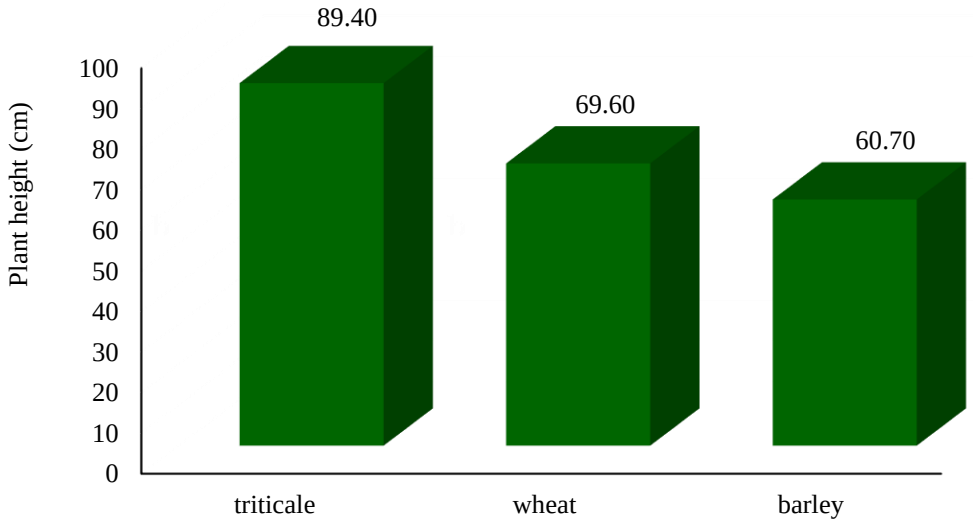


Fig 5. Average plant height in regionsSpike length

According to Table (3), there was a highly significant difference ($p < 0.01$) in spike length between the two regions. The Bastam region (non-saline), with an average spike length of 9.3 cm, ranked in the superior statistical group, while the Tal region (saline stress), with an average length of 7.5 cm, was placed in a lower statistical group. These findings indicate that severe salinity stress reduced spike length by 19.25% (Fig. 6). The significant reduction in spike length under saline irrigation can be linked to osmotic stress and ion toxicity, which restrict water uptake and inhibit reproductive development. Similar results have been reported by Munns and Gilliham (2015).

Irrigation water salinity significantly affected spike length in the experimental treatments. Mihan wheat exhibited the lowest percentage of spike length reduction (11.94%), while Bahman barley showed the highest reduction (25.78%). As salinity increased, the percentage of spike length reduction was 22.33%, 19.81%, and 17.27% for barley, triticale, and wheat, respectively. Therefore, with increasing salinity, the highest percentage of spike length reduction was associated with barley, followed by triticale and wheat (Fig. 7).

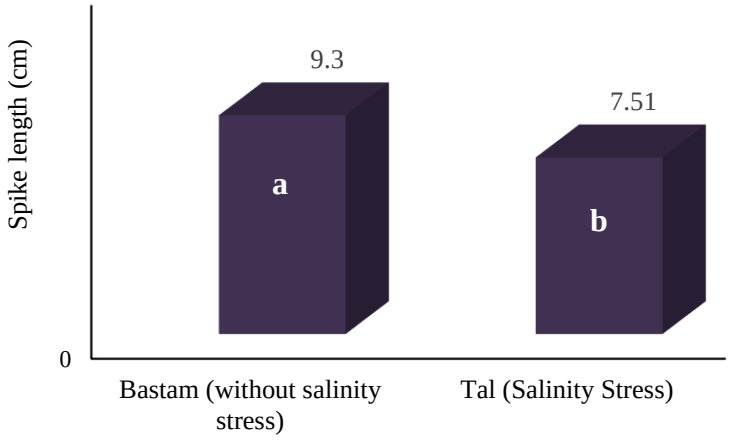


Fig. 6- Average spike length in regions

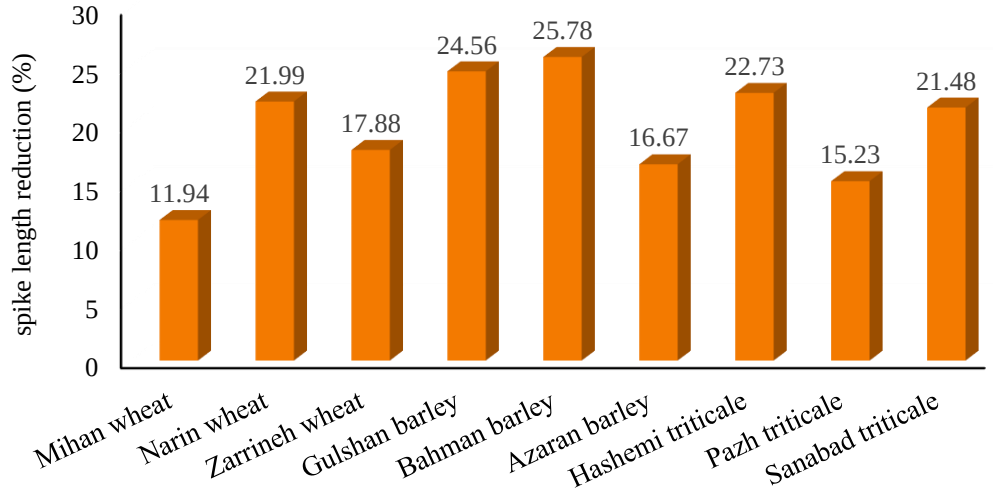


Fig. 7- Average percentage of spike length reduction in experimental treatments in regions

The composite analysis of spike length results revealed highly significant differences ($p < 0.01$) among the experimental treatments. The Sanabad triticale treatment, with a spike length of 11.1 cm, ranked in the superior statistical group. The Paj triticale, Hashemi triticale, Zarrineh wheat, Narin wheat, Azaran barley, Mihan wheat, Bahman barley, and Golshan treatments, with average spike lengths of 9.95, 9.75, 9.1, 9.1, 8.58, 8.11, 4.5, and 5.46 cm, respectively, were placed in the other statistical groups (Fig. 8).

The spike length of triticale, wheat, and barley crops was examined. Triticale exhibited the highest spike length at 10.27 cm. Triticale spikes were 18.6% and 77.8% longer than those of wheat and barley, respectively. Furthermore, the spike length of wheat was significantly greater than that of barley (Fig. 9).

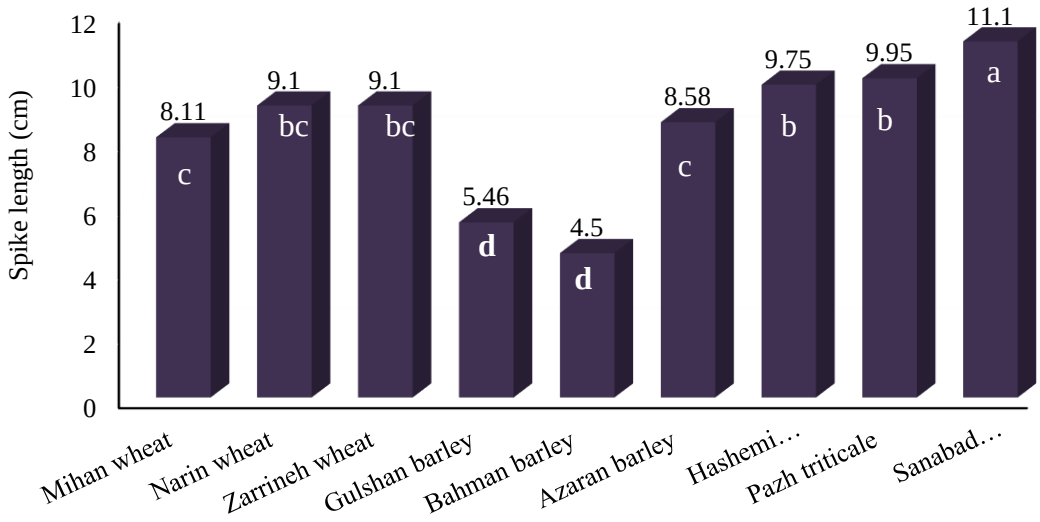


Fig. 8- Average spike length of experimental treatments in two regions

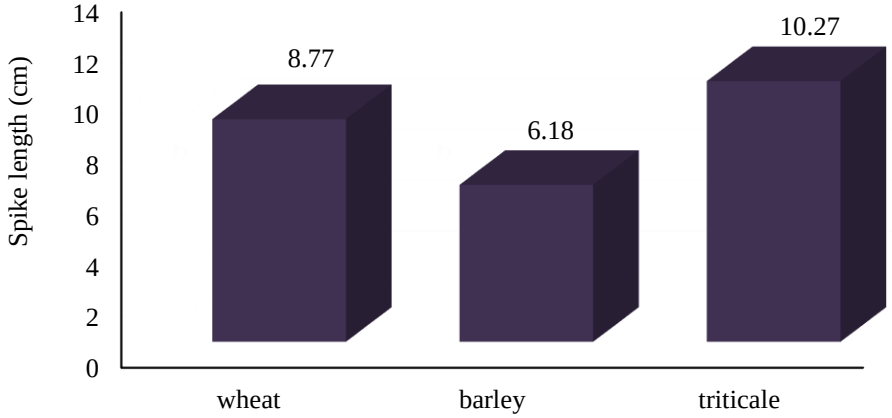


Fig. 9- Average spike length in regions

Yield

The results presented in Table 3 indicate that the effect of irrigation water quality on fresh forage yield was highly significant across the different regions ($p < 0.01$). The Bastam region (non-saline), with an average fresh forage yield of 60.33 tons per hectare, ranked in the superior statistical group, while the Tal region (saline stress), with an average yield of 17.38 tons per hectare, was placed in a lower statistical group. Salinity stress in the Tal region (Region 2) caused a 71.2% decrease in fresh forage yield compared to the Bastam region (Region 1, non-saline) (Fig. 10).Similarly, Munns and Gilliham (2015) reported that salinity stress reduces plant yield through osmotic stress, specific ion toxicity (particularly Na^+ and Cl^-), and nutrient imbalance.

It should be noted that, since this research was conducted in two regions with two different irrigation methods (drip irrigation in the Bastam region and border irrigation in the Tal region), factors other than salinity may have contributed to the observed differences between the two sites, including irrigation method, soil texture, drainage conditions, and local microclimate (temperature, evapotranspiration, and relative humidity). Consequently, the differences in yield (60.3 vs. 17.4 t/ha) cannot be attributed solely to irrigation water salinity. Disentangling the individual contribution of each factor requires further controlled researches.

Fig. (11) illustrates the fresh forage yield of the experimental treatments in the Bastam and Tal regions. The percentage of reduction in fresh forage yield across the experimental treatments ranged from 52.8% to 78.2%. Triticale Sanabad and wheat Mihan exhibited the highest reduction in fresh forage yield (78.0%), while barley Azaran showed the lowest reduction (52.8%) (Fig. 12). The reduction in fresh forage yield for triticale, wheat, and barley crops was 74.99%, 73.32%, and 61.62%, respectively. Therefore, with increasing salinity, the highest percentage of reduction in fresh forage yield was associated with triticale, followed by wheat and barley (Fig. 12).

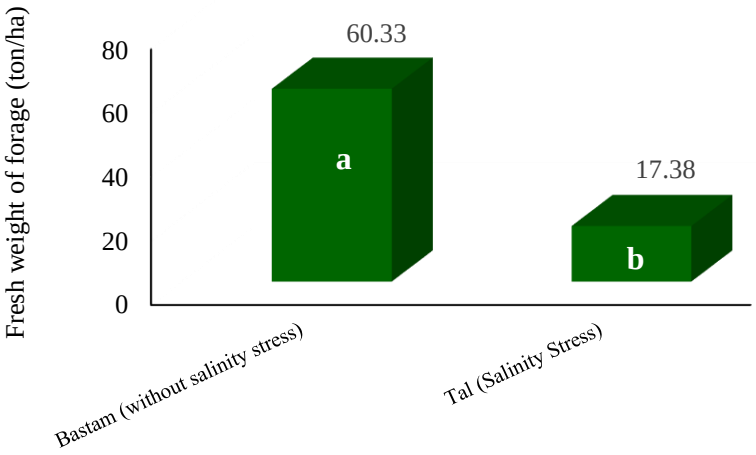


Fig. 10- Average fresh forage yield in different regions

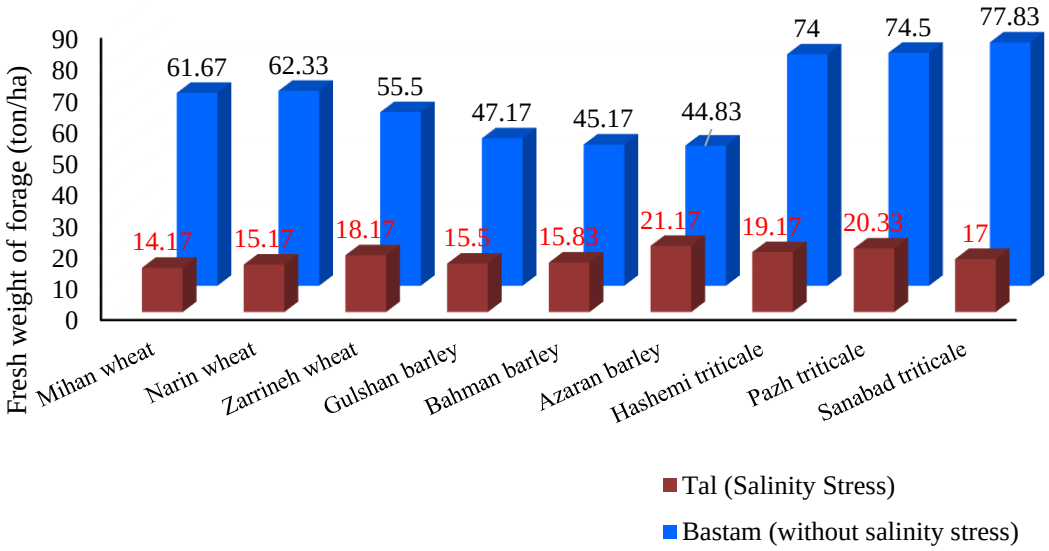


Fig. 11- Fresh forage yield of experimental treatments in region

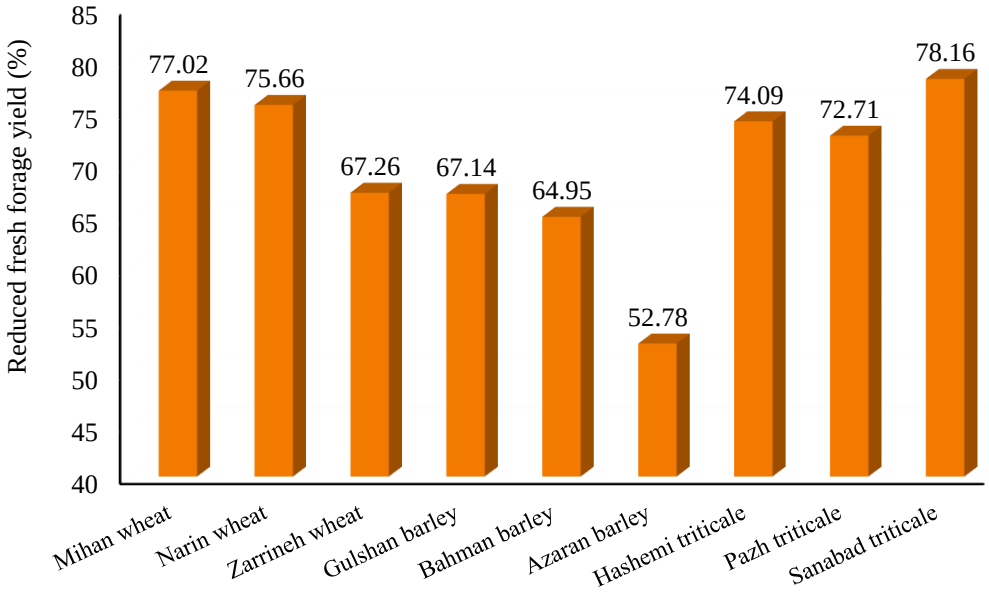


Fig. 12- Average percentage reduction in fresh forage yield in experimental treatments in regions

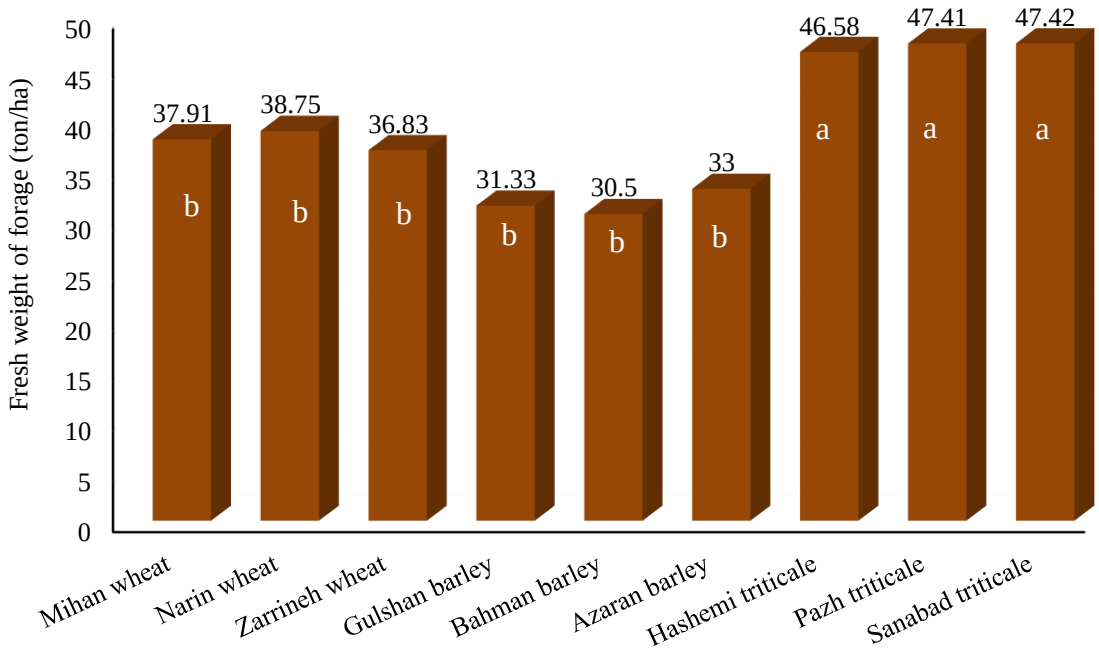


Fig. 13- Average fresh forage yield in experimental treatments in regions

The effect of irrigation water salinity on the yield of forage types and varieties was highly significant ($p < 0.01$) (Table 3). The range of this trait varied from 30.5 to 47.42 tons per hectare. The triticale treatments Sanabad, Paj, and Hashemi, with average yields of 47.42, 47.41, and 46.58 tons per hectare, respectively, were ranked in the superior statistical group due to their highest yields. Narin wheat, Mihan wheat, Zarrineh wheat, Azaran barley, Golshan, and Bahman barley were placed in the other statistical groups, with average yields of 38.75, 37.91, 36.83, 33, 31.33, and 30.5 tons per hectare, respectively (Fig. 13).

The results showed that the average fresh forage yield for triticale, wheat, and barley was 47.14, 37.83, and 31.61 tons per hectare, respectively. Triticale exhibited the highest fresh forage yield, producing 24.60% and 49.12% more yield than wheat and barley, respectively. Furthermore, the fresh forage yield of wheat was 19.68% higher than that of barley (Fig. 14). Based on these results, the cultivation priority for autumn forage production is triticale, followed by wheat and barley. These findings indicate that triticale can perform well under saline conditions and produce significant biomass. The results of this study are consistent with the findings of Massimi et al. (2016) and Farooq et al. (2015).

Forage Crude Protein

The results indicated that irrigation water quality had a significant effect on the crude protein percentage of all studied forage varieties. A significant difference was observed between the two regions ($p < 0.01$) (Table 9). The Bastam region (non-saline) had a mean crude protein content of 10.17% and was classified in the superior statistical group, whereas the Tal region (salinity stress) had a mean value of 7.49% and was placed in the lower statistical group. Comparison of means indicated that irrigation water salinity reduced forage crude protein by 26.35% compared with non-saline conditions (Fig. 15).

The reduction in protein content under saline conditions can be attributed to the adverse effects of salinity stress on nutrient uptake, particularly nitrogen, and the disruption of protein metabolism. Salinity stress impairs physiological and metabolic processes, limiting nitrogen absorption and consequently reducing protein synthesis in plant tissues (Guo et al., 2024).

Under non-saline conditions (Bastam region), crude protein ranged from 9.09% to 11.77%. The highest value was recorded for the Sanabad triticale variety (11.77%), followed by Paj triticale (10.88%), while the lowest value was observed in the Zarrineh wheat variety (9.09%). The significant differences among varieties indicate that the response to salinity is strongly influenced by genetic characteristics. Under salinity stress, however, the relative advantage shifted toward certain barley cultivars, particularly Azaran. This response may be attributed to the inherently greater salinity tolerance of barley and its superior capacity to maintain ionic balance, osmotic regulation, and nitrogen metabolism stability (Ghonaim et al., 2023).

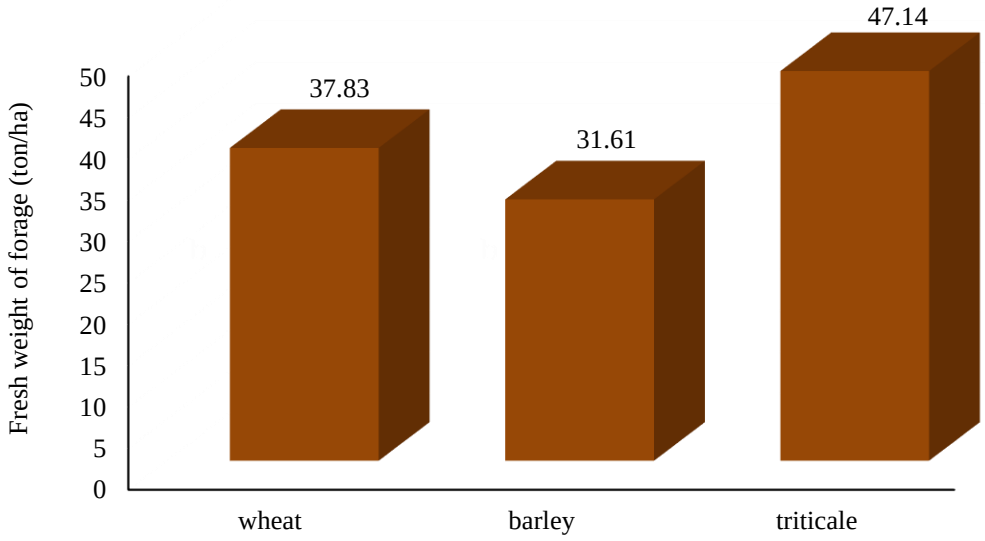


Fig. 14- Average fresh forage yield in regions

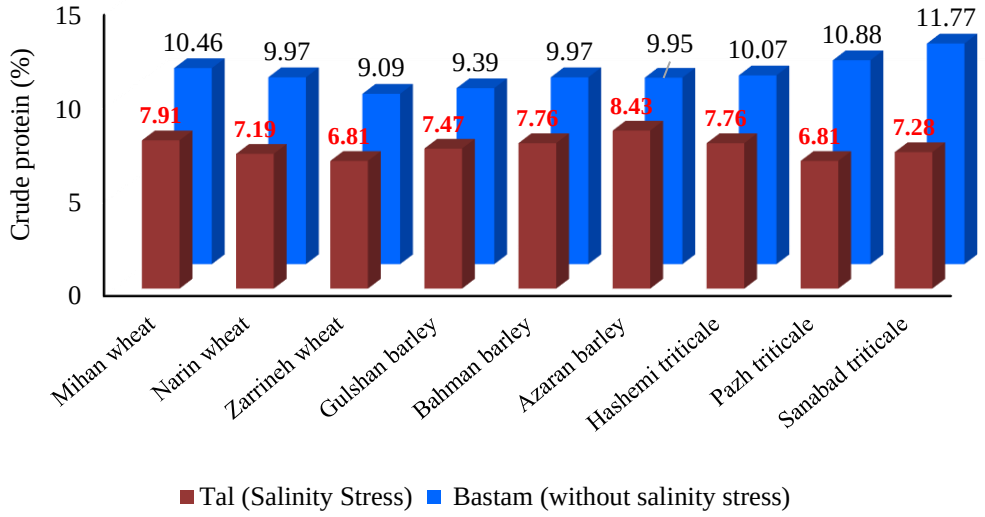


Fig. 15- Average protein of regions

Water Productivity

The effect of irrigation water salinity on water productivity was statistically significant ($p < 0.01$) in both study regions (Table 3). The Bastam region (non-saline), with an average water productivity of 10.72 kg/m³, ranked in the superior statistical group, while the Tal region (saline stress), with an average water productivity of 2.34 kg/m³, was placed in the lower statistical group. Salinity stress caused a 78.2% decrease in water productivity (Fig. 16). These findings are consistent with those reported by Qadir et al. (2014), who demonstrated that elevated salinity in irrigation water negatively affects forage yield, yield components, biomass accumulation, and ultimately water productivity. The results confirm that salinity stress substantially reduces the water productivity in forage production systems under semi-arid conditions.

Fig. (16) illustrates the water productivity of the experimental treatments in the Bastam and Tal regions. Water productivity in the Tal region (saline stress) decreased significantly compared to the Bastam region (non-saline stress). The reduction in water productivity for wheat, triticale, and barley crops was 77.70%, 76.17%, and 71.01%, respectively. Therefore, with increasing salinity, the highest percentage of water productivity reduction was associated with wheat, followed by triticale and barley. Fig. (17) presents the water productivity in the two regions. Mihan wheat exhibited the highest percentage of water productivity reduction (80.22%), while Azaran barley showed the lowest reduction (78.52%) (Fig. 18).

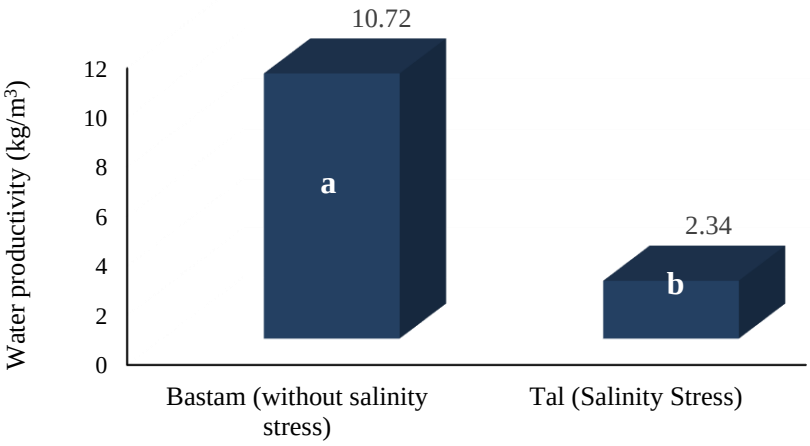


Fig. 16- Average water productivity in different regions

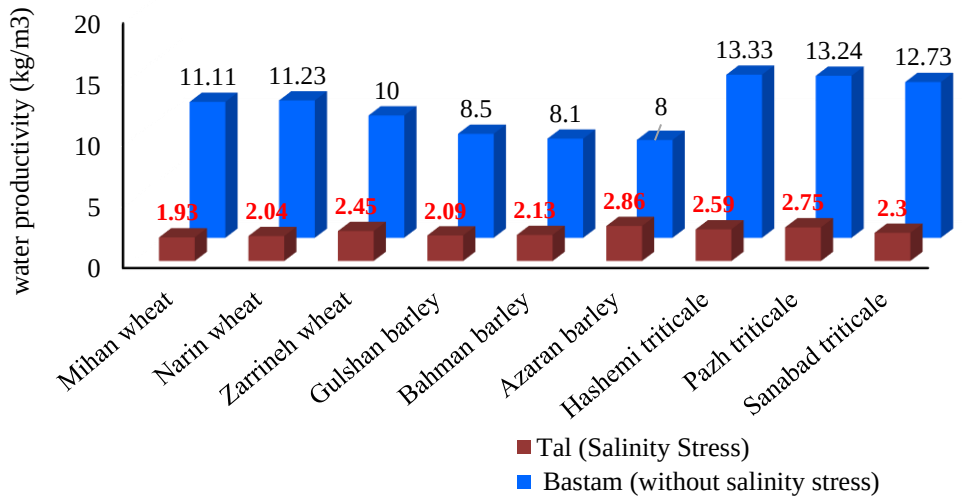


Fig. 17- Water productivity of yield

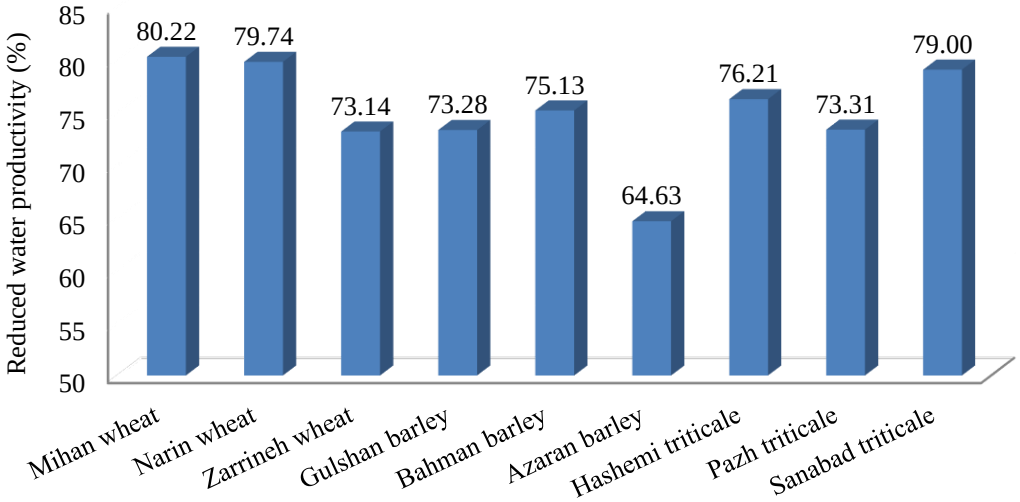


Fig. 18- Average percentage reduction in fresh forage yield in experimental treatments in regions

The effect of water salinity on water productivity in the experimental treatments was significant ($p < 0.01$). The triticale treatments Paj, Hashemi, and Sanabad, with average water productivity of 8.08, 7.96, and 7.51 kg/m³, respectively, were ranked in the superior statistical group due to their highest productivity. The treatments of Narin wheat, Mihan wheat, Zarrineh wheat, Azaran barley, Golshan barley, and Bahman barley were placed in the subsequent statistical groups, with average water productivity of 6.63, 6.51, 6.22, 5.47, 5.29, and 5.13 kg/m³, respectively (Fig. 19).

Analysis of the experimental forage groups indicated that triticale, wheat, and barley had water productivity of 7.85, 6.45, and 5.30 kg/m³, respectively. Triticale forage exhibited the highest water productivity, with values 21.6% and 48.2% higher than those of wheat and barley, respectively. Furthermore, water productivity in wheat was 21.8% higher than that of barley (Fig. 20). Based on the results of this study, in terms of water productivity, the cultivation priority for both saline and non-saline areas is triticale, followed by wheat and barley.

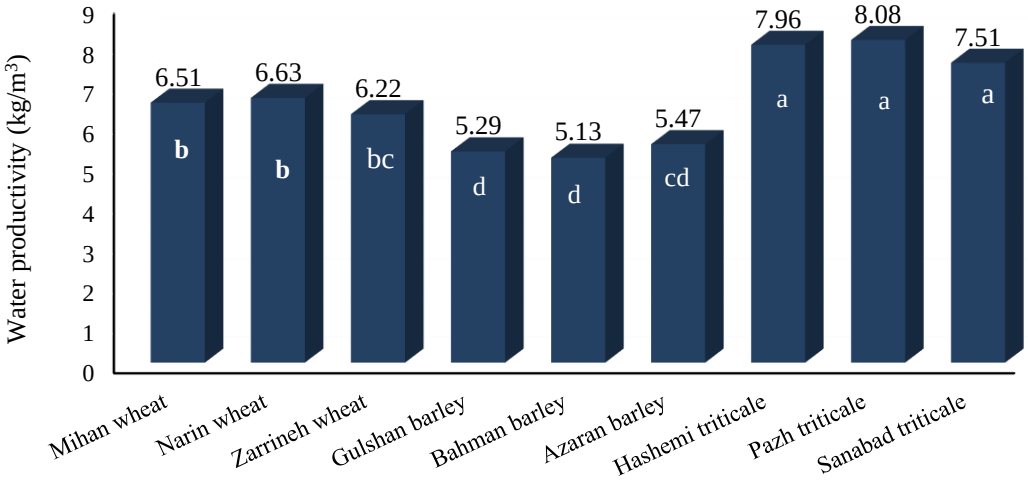


Fig. 19- Average fresh forage water productivity in experimental treatments in regions

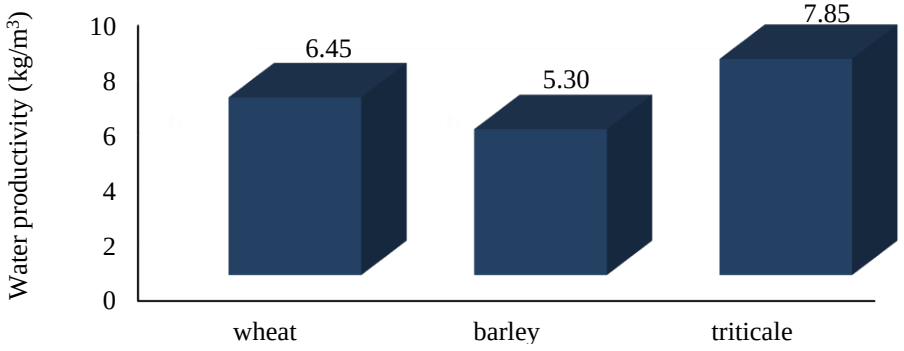


Fig.20 - Average water productivity of crops in regions

Water Use

Table (4) shows the volume of irrigation water applied during the study years. The average volume of irrigation water applied during the growing season was 5,100 m³/ha in the Bastam region and 6,950 m³/ha in the Younes Abad region (Tal, south of Shahrood).

Table 4 – Irrigation water volume in the years of research

Location	EC irrigation water (dS/m)	Irrigation method	Water volume (m^3/ha)
1	1.151	Tape irrigation	5100
2	12.650	Border (strip) irrigation	6950

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Conclusions

Forage production is a fundamental requirement for livestock farming in Semnan province. Currently, forage cultivation is predominantly conducted during the summer, a period coinciding with high evapotranspiration and peak water demand by orchards and other crops, leading to significant water resource challenges. Shifting forage production to the autumn season presents an effective strategy to alleviate pressure on water resources during spring and summer. Furthermore, autumn cultivation reduces overall production costs by eliminating the expenses associated with forage ensiling. Given that Semnan province is characterized by a hot and dry climate, water scarcity, and inherent soil and water salinity, the adoption of drought- and salt-tolerant forage species is essential for sustainable agriculture.

Based on quantitative parameters, growth characteristics, and forage quality, triticale exhibited the highest priority for cultivation under both saline and non-saline conditions, followed by wheat and barley. Among the studied cultivars, triticale cultivars Paj, Hashemi, and Sanabad, along with the wheat cultivar Narin, demonstrated superior performance and are therefore recommended as the preferred choices for forage production in Semnan province to ensure resilience against both drought and salinity stresses.

Recommendations

Given the specific climatic conditions in Semnan Province (high evaporation and temperature, water shortage and salinity of water and soil in large parts of the province), it is necessary to cultivate drought and salinity resistant forage plants in the autumn and spring seasons. Therefore, more necessary and targeted research should be conducted on these and other autumn forages.

Conflict of Interest

The author declared no potential conflicts of interest concerning the research, authorship, and publication of this article.

Confirmation.

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Data Availability Statements

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contribution

Seyed Hassan Mousavi Fazl is the single author who is responsible for overall contributions.

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