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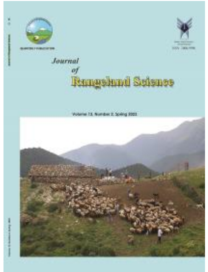

**Research and Full Length Article:**

# Investigation of Feasibility and Effect of Alternative Farming System on the Grain Yield of Barley and Forage Production in Western Semi-arid Region of Golestan Province, Iran

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**Abstract.** One of the major challenges in semi-arid regions of Iran is to supply the adequate forage for livestock and meanwhile prevent the destruction of rangelands due to overgrazing. Therefore, this study aimed to compare three cropping systems of barley using *Salsola turcomanica* (ST), and *Chrysopogon zizanioides* (CZ) in three treatments of barley+ST, barley+ST+CZ and mono-culture of barley. Two-year field trials data were collected from November 2018 to October 2020 in two experimental sites using a Randomized Complete Block Design (RCBD) with four replications. The results of analysis of variance over two years indicated that the effects of year, location, and year by location interaction were significant ($p<0.01$) for all of barley's yield components. Mixed cropping of barley with other species had no negative effect on barley traits such as grain yield, straw yield and harvest index. In addition, the mixed cropping of barley+ST and barley+ST+CZ in the first year produced 2.5 t/ha more forage yield than that mono-culture of barley. This was due to high production of *Salsola* (ST), in mixed cropping. In both years, yield of Salsola production was about 25% of whole produced biomass. Drastic reduction in rainfall in the second year reduced the obtained yield; so, there was no significant difference among three cropping systems in the second year. However, cropping systems of barley+ST and barley+ST+CZ produced about 1 t/ha more forage than that for the mono-culture of barley. Mixed cropping of barley +ST+CZ did not affect yield components of barley. Mixed cropping of barley with *Salsola turcomanica* could guarantee soil cover throughout the year and is recommended for forage production in rangeland in Iran.

**Key words:** Barley, *Salsola turcomanica*, *Chrysopogon zizanioides*, Mixed cropping

## Introduction

Humanity is heading toward the major challenge of having to increase food production by about 50% by 2050 to cater for 3 billion inhabitants. This is along with shrinking and degradation of soil and water resources scarcity and uncertainty due to climate change (Vadez *et al*., 2012). Demand for food and forage increases as human and animal populations in arid and semi-arid regions increase. Low precipitation and its improper temporal distribution in addition to low soil fertility have led to low agricultural production in these regions (Rao *et al*., 1997). Alternative farming system that uses all of environmental potentials of arid and semi-arid regions can contribute substantially to protect the soils from further degradation and to increase food and forage production. This alternative farming system can be used as an insurance against yield failures by frequent droughts. One of those alternative farming systems is ley farming. The term "ley farming" refers to arable crops alternation with forage plants (Nasrollahi *et al*., 2017).

Soil secondary salinization and the occurrence of the summer–autumn forage shortage of livestock are the most general limitations of Australian arable lands (Edwards *et al*., 2019). These restrictions are in accordance with the challenges and concerns of sustainability mentioned by Crews *et al*. (2016). In the mid 1930's, self-regenerating annual species such as *Trifolium subterraneum* L. and *Medicago spp*. were added into southern Australian cereal farming systems along with addition of superphosphate, enhanced soil fertility and led to higher cereal yields and livestock production (Puckridge and French, 1983). Nowadays, alley farming in Australia includes crop: pasture sequences of 1:1; 2:1, 3:1 and even 4:1 (Edwards *et al*., 2019). The "ley" systems are commonly used in Brazil, Argentina, Colombia, and Australia with positive outcomes (Nasrollahi *et al*., 2017). Higher cereal yield and forage production, lower use of inorganic fertilizers, better soil quality, carbon fixation and lower erosion are some of ley farming system advantages (Hohnwald *et al*., 2000; Navas *et al*., 2011). It is believed that many of degraded arid and semi-arid ecosystems can be successfully rehabilitated and cultivated using halophyte plants. A kind of ley farming system using native tolerant plant species along with barley can be applied for forage production. Because of their diversity, halophytes have been regarded as a rich source of potential new crops. Halophytes have been tested as vegetable, forage, and oilseed crops in agronomic field trials (Glenn *et al*. 1998). These species have a high potential for forage production and are considered as a proper, cheap and practical option for the forage production in the developing countries (Squires and Ayoub, 1994; Arrekhi *et al.*, 2021). Interest is increasing in the use of these potential and available livestock fodder plant species in Iran due to the large extension of degraded lands and abundance halophyte species in this country (Kashki *et al.*, 2016). Major plant species in the salt-affected ecosystems in arid and semi-arid regions are from Chenopodiaceae family (Gintzburger *et al*., 2003). In this family, the most diverse genus of the sub-family Salsoloideae in Central and Middle Asia is Salsola which has about 100 species, of which 48 species are found in the Iranica flora (Bakhshi-Khaniki & Mohamadi, 2012). Several features such as high fodder value and biomass production potential, abundant seed production, and high tolerance to extreme climatic stress like the drought and salinity due to deep root system, high osmosis pressure and high efficiency of water consumption are the reasons toward their success as a potential forage species in arid and semi-arid ecosystems (Pasandi *et al.*, 2017; Gintzburger *et al*., 2003; Hanif *et al*, 2018). Forage production of different salsola species has been reported from 0.1

to 2 ton/ha (Bakhshi-Khaniki and Mohammadi, 2011; Dwyer and Wold-Yohnnis, 1972; Akhani and Ziegler, 1997; Gitzenburger *et al*., 2003). *Salsola turcomanica* (Litv) along with *Plantago coronopus* L, *Halostachys caspica*, *Halocnemum strobilaceum*, and *Frankenia hirsuta* are relatively palatable halophyte species of the study area (Turkmen Sahra in the northern part of Iran). *S. turcomanica* has relatively high protein content and dry matter digestibility and according to the native stockholders statement, this species has an important role in forage and salt supply for goats and camels during the late autumn (Arrekhi *et al*, $2021_b$; Arrekhi *et al*, 2020 and Ranjbar, 2002).

Vetiver grass (*Chrysopogon zizanioides)* is a plant from poaceae family which was introduced in the 80s decade in India by World Bank to water and soil conservation (Kenthorai-Roman *et al*, 2018 and Ahmadi-Bani *et al*., 2016). Nowadays, this plant plays an important role in the management of degraded lands due to its unique characteristics such as the ability to grow in different soil types and adaptation to different climates. This plant has been used in many parts of the world as bio-engineering technique to restoration of vegetation, control of erosion, feeding livestock, soil fertility enhancement and carbon sequestration (Troung *et al*., 2007). The stems of this plant can grow fast and can reach a length of 2 m and its leaves are a good source of forage for feeding livestock (Kenthorai-Roman *et al.*, 2018).

The problems of animal food supply are intensified in the arid and semi-arid regions with harsh environment and scarce and erratic precipitation that limits the growth of herbaceous species and biomass production in rangelands (Ahmadi-Beni *et al*., 2014). In order to find a solution for feeding the livestock in semi-arid, poor arable lands of Golestan province, Iran, in the warm seasons of year when there is no plant cover on the soil, a new cropping system using native and non-native plant species was tested. Therefore, this study investigates the feasibility and effect of alternative cropping system (mixed cropping of barley, *Salsola turcomanica* and *Chrysopogon. zizanioides*, on Silt loam and Sandy clay loam soils from the semi-arid region of Golestan province, Iran, on the yield components of barley (cultivar Sahra), and potential of native and non-native plant species in terms of forage production.

## Materials and Methods

### Experimental sites

The study sites (Mangali 37°10' 01" N, 54°24'24"E and Bandar Torkaman 36°55'20"N, 54°06'20"E) are located in the western Golestan province in Iran (Fig. 1).

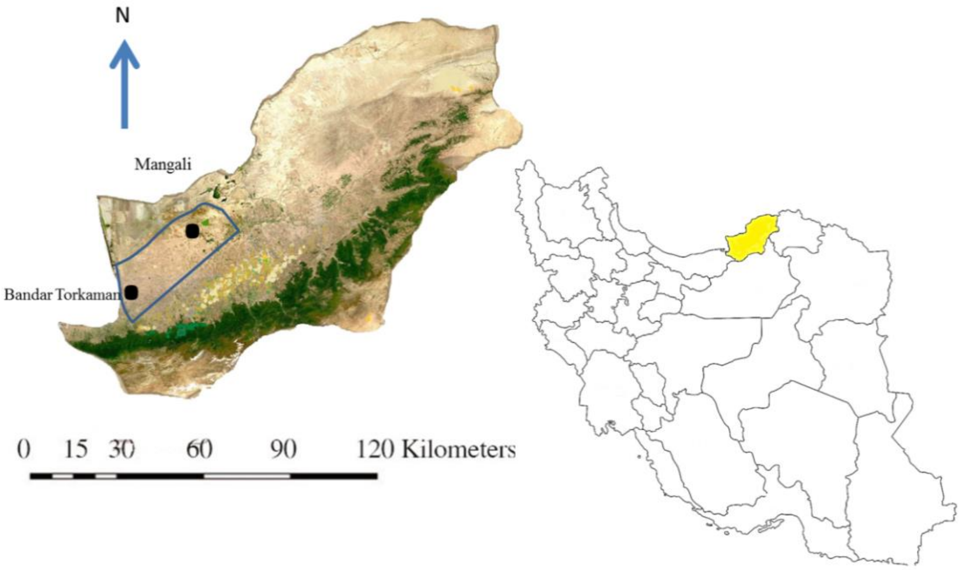


**Fig. 1.** Location map of experiment fields in North of Iran

Slope gradient of this region is nearly flat (1-2%) at an altitude between -24 and -10 m above sea level (Niknahad-Gharmakher *et al*., 2017). The average annual temperature is 16.6°C; the extreme high and low seasonal temperatures are 48°C in summer and -6°C in winter, respectively. The average annual rainfall is 410 mm in Bandar Torkaman and 320 mm in Mangali (Table 1). Rainy seasons extend generally from October to May, and the dry season extends from June to October (Fig. 2). The main crop in this region is barley (Mirzaali *et al*., 2006). The natural growth form of this region is halophyte shrubs and grasses such as *Salsola sp., Halostachys blanyesiana, Puccinellia distance, Halocnemum strobilaceum, Aeluropus littoralis* and *Aeluropus lagopoides* (Niknahad-Gharmakher *et al*., 2015; Niknahad-Gharmakher *et al*., 2017).

The first-year annual rainfall in two study sites was higher than the long-term average (10-year) rainfall while it was slightly lower in the second year of field trial (Figs. 3 and 4). Monthly mean rainfall in the first year on Mangali from November to June was higher than 10-year monthly mean of this site. In the second year, rainfall was equal or slightly lower than recorded 10-year monthly mean (Fig. 3). Monthly mean rainfall in the first year on Bandar Torkaman from December to May was higher than 10-year monthly mean of this site. In the second year, the higher rainfall than 10-year monthly mean was recorded in October, February, April and May (Fig. 4).

## Preparation the seeds of *Salsola turcomanica*

Seeds of *S. turcomanica* were collected in autumn 2017 in Bandar Torkaman County, Iran. After seed collection, the healthy, mature, intact seeds were stored at 4°C. The viability of seed sample was tested using the tetrazolium chloride (TTC) staining technique (Esno *et al.*, 1996). The result demonstrated that *S. turcomanica* seeds have 98% viability. To optimize its germination, the seeds were scarified using sand paper (Arrekhi *et al*., 2020). Prior to the setting-up of the experimental design, 3 soil samples (0–20 cm) were taken from each of the experimental sites to measure their physico-chemical properties (Table1).

**Table 1.** Soil physio-chemical properties for experimental sites and annual rainfall and temperature

| Site | pH | Ec (dS/m) | Soil Texture | Annual Precipitation (mm) | Annual Temperature (°C) |
|---|---|---|---|---|---|
| Mangali | 7.9 | 13.7 | Silt loam | 320 | 16.6 |
| Bandar Torkaman | 7.1 | 6.03 | Sandy clay loam | 410 | 16.6 |

Field experiment studies were using three treatments of (pure barley, barley+*Salsola turcomanica* (ST), barley+*Salsola turcomanica* (ST)+*Chrysopogon zizanioides* (CZ) with four replications based on RCBD in two experimental sites (Fig.1). Size of plots was (8×5 m). Data were collected over two years from 2018 to 2020. Every year, barley and *S. turcomanica* were sown (200 kg/ha for barley and 15 Kg/ha for *Salsola*) in the mid-November in both experimental sites. In 2018, *C. zizanioides* clones were propagated in pots in the greenhouse and then were transplanted to the experimental sites to grow in the late November in 6 m row intervals in barley+ST+CZ plots. CZ was replanted in Mangali in the following year due to the dying of the plants. In both sites, Barley and ST were harvested at maturity stage in October. CZ was cut two times per year at the end of June and September only in Bandar Torkaman. Data were collected for barley grain and straw yield in each plot. Barley biomass was calculated as the sum of grain and straw yield. Harvest index was obtained as ratio of grain weight and biomass weight. Total biological yield of each plot was summed of aerial parts of barley+ST+CZ in the end of their growing season.

## Statistical analysis

The collected data were combined in an analysis between sites over 2 years for barley yield components and sum of biological yield of three species. Means comparison was made among treatments using Tukey test. All statistical analysis was performed using the SPSS$_{21}$ statistical software.

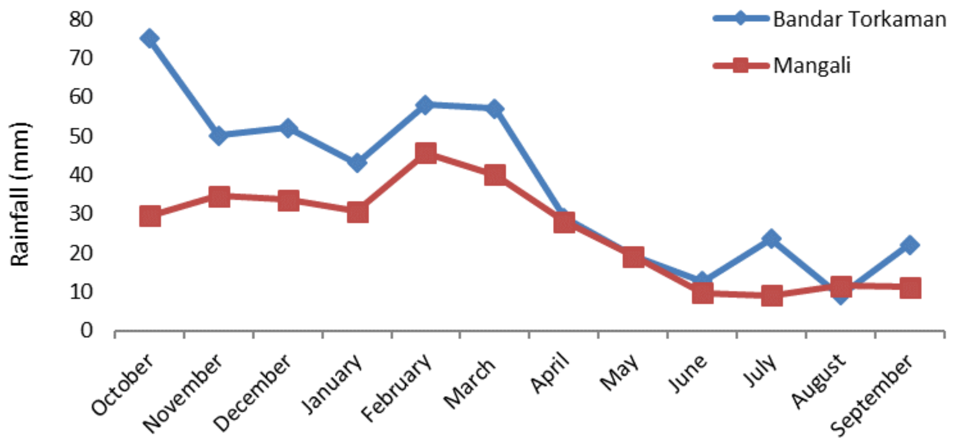


**Fig. 2.** Rainfall pattern in Bandar Torkaman and Mangali sites in different months (2010-2020)

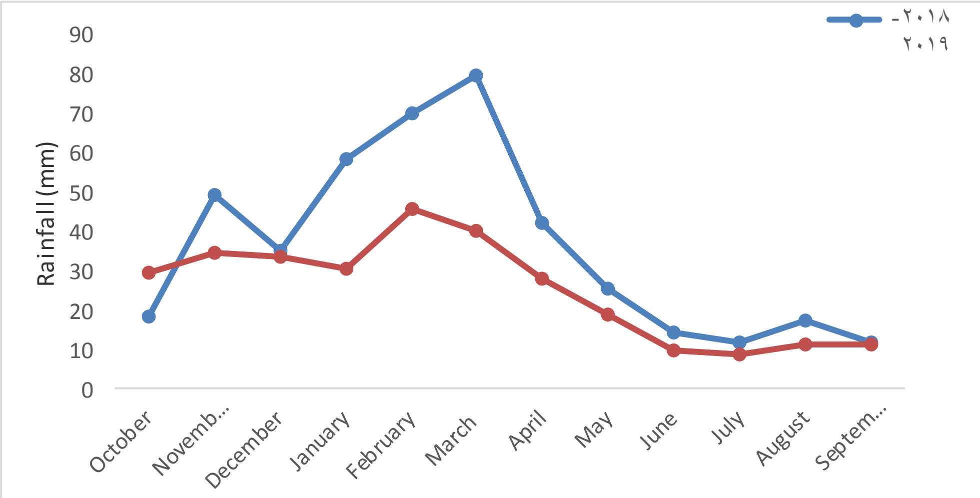


**Fig. 3.** Rainfall pattern in Mangali site in two years of field trial

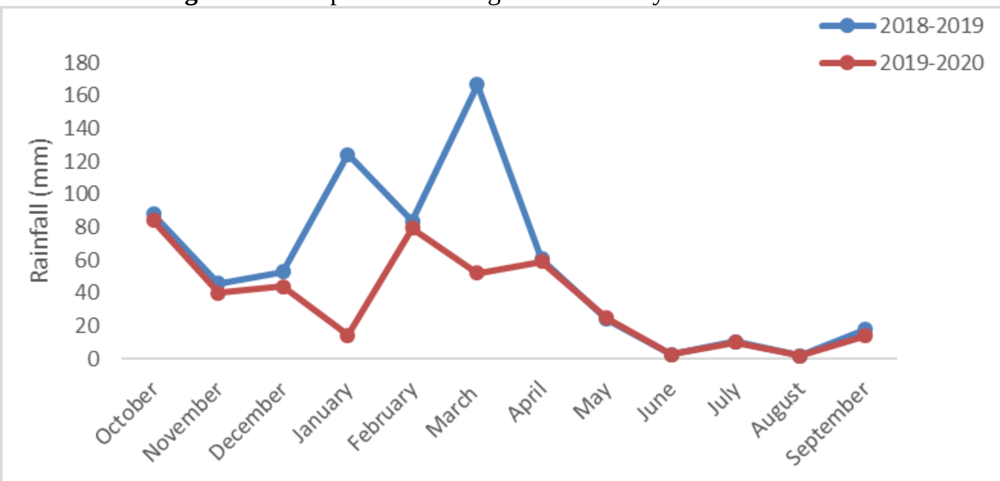


**Fig 4.** Rainfall pattern in Bandar Torkaman site in two years of field trial

## Results

The results analysis of variance demonstrated that location and year have a significant ($p<0.01$) effect on all of barley's yield components, so barley's yield components between two locations and two years were significantly different ($p<0.01$). The year by location interaction effects were significant ($p<0.01$) for barley biological yield, straw yield and harvest index which indicate different responses of traits in 2 locations over 2 years. The effect of treatment was significant only for total biological yield ($p<0.01$) indicating that the mixed cropping has no effect on barley's grain yield, straw yield and harvest index. The interaction of Treatment×Year, Treatment×Location, and Treatment×Location×Year on all of barley's yield components was not significant ($p>0.05$) (Table 2).

**Table 2.** Mean Square (MS) from the combined analysis of variance for total produced biological yield and yield components of barley in two years and two locations

| S.O.V | df | Biological yield | Barley grain yield | Barley biomass | Barley straw yield | Barley Harvest Index |
|---|---|---|---|---|---|---|
| Location | 1 | 219.30 ** | 117.34 ** | 183.61 ** | 2.53 ** | 0.32 ** |
| Year | 1 | 8.807 ** | 4.03 ** | 7.05 ** | 0.07 ** | 0.155 ** |
| Year × Location | 1 | 0.508 ** | 0.001 ns | 0.213 ** | 0.506 ** | 0.045 ** |
| Error 1 | 12 | 0.037 | 0.55 | 0.047 | 0.021 | 0.00 |
| Treatment | 2 | 0.066 ** | 0.053 ns | 0.12 ns | 0.036 ns | 0.001 ns |
| Treatment ×Year | 2 | 0.017 ns | 0. 36 ns | 0.005 * | 0.0309 ns | 0.00 ns |
| Treatment × Location | 2 | 0.092 ns | 0.031 ns | 0.077 ns | 0.92 ns | 8.125 ns |
| Treatment × Location × Year | 2 | 0.04 ns | 0.046 ns | 0.019 ns | 0.001 ns | 7.50 ns |
| Error 2 | 24 | 0.480 | 0.540 | 0.059 | 0.250 | 0.001 |
| CV (%) | | 23.26 | 22.63 | 38.7 | 23.39 | 13.91 |

n.s & **: Non-significant & significant at α= 0.01, respectively

## Barley grain yield

In the first year of trial in Bandar Torkaman site, application of alternative farming system had a significant effect on barley grain yield ($p<0.05$), so its mean ranged from 3.37 ton/ha in the control (mono-culture of barley) to 4.18 ton/ha in the system of barley+ST (*S. turcomanica*)+CZ (*C. zizanioides*) and 4.12 ton/ha in barley+ST (*S. turcomanica*), respectively (Table3). In the second year, application of alternative farming system had no significant difference ($p>0.05$) on barley grain yield among three treatments. The lowest grain yield with the value 1.76 ton/ha was observed in the control (mono-culture of barley) and the highest one was recorded in barley+ST with the value of 2.01 ton/ha.

Application of alternative farming system for two consecutive years in Mangali had no significant effect ($p>0.05$) on barley grain yield (Table3). In the first year, barley grain yield ranged from 2.99 ton/ha in the control (pure barely) to 3.33 ton/ha in barely+ST and 3.45 ton/ha in the barely+ST+CZ treatment, respectively. In the second year, barley grain yield ranged from 1.19 ton/ha in (pure barley) to 1.15 ton/ha in the barely+ST and 1.52 ton/ha in barely+ST+CZ treatment, respectively (Table3).

## Barley straw yield

Application of alternative farming system for two consecutive years in Bandar Torkaman had no significant ($p>0.05$) effect on barley straw yield. In the first year, barley straw yield ranged from 2.87 ton/ha in the control plots to 3.12 ton/ha in the barely+ST and 3.13 ton/ha in the barely+ST+CZ plots. In the second year, its mean ranged from 1.91 ton/ha in the control plots to 2.15 ton/ha in the barely+ST+CZ plots and 2.23 ton/ha in the barely+ST plots (Table3).

In Mangali the application of alternative farming system for two consecutive years had no significant ($p>0.05$) effect on barley straw yield. In the first year of trial, barley straw yield ranged from 1.09 ton/ha in the barely+ST plots to 1.21 ton/ha in the control plots and 1.24 ton/ha in the barely+ST+CZ plots. In the second year, its mean ranged from 1.29 ton/ha in the B+ ST plots to 1.36 ton/ha in the control and 1.74 ton/ha in the B+ST+CZ plots (Table3).

## Barley biomass

Application of alternative farming system for two consecutive years in Bandar Torkaman had no significant effect ($p>0.05$) on barley biological yield. In the first year, barley biological yield ranged from 6.25 (ton/ha) in the control plots to 7.25 (ton/ha) in the barely+ST plots and 7.31 (ton/ha) in the barely+ST+CZ plots. In the second year, its mean ranged from 3.69 (ton/ha) in the control plots to 4.13 (ton/ha) ha in the barely+ST+CZ plots and 4.24 (ton/ha) in the barely+ST plots (Table 3).

In Mangali, the application of alternative farming system for two consecutive years had no significant effect (p>0.05) on barley biological yield. In the first year, barley biomass ranged from 4.20 (ton/ha) in the control plots to 4.42 (ton/ha) in the barely+ST plots and 4.69 (ton/ha) in the barely+ST+CZ plots. In the second year, its mean ranged from 2.44 (ton/ha) in the barely+ST plots to 2.55 (ton/ha) in the control (mono-culture of barley) plots and 3.26 (ton/ha) in the barely+ST+CZ plots (Table 3).

## Barley Harvest Index (HI)

Application of alternative farming system for two consecutive years in Bandar Torkaman had no significant effect (p>0.05) on barley HI. In the first year of trial, barley harvest index ranged from 54% in the control plots to 57% in the barely+ST and barely+ST+CZ plots. In the second year, its mean was about 48% for all three treatments (Table3).

In Mangali, the application of alternative farming system for two consecutive years had no significant effect (p>0.05) on barley harvest index. In the first year of trial, barley harvest index was 73% for all three treatments. In the second year, its mean decreased drastically to 47% for all three treatments (Table3).

## Total Biological yield

Application of alternative farming system for two consecutive years in Bandar Torkaman had a significant effect on biological yield (p<0.05). In the first year, its biological yield ranged from 6.25 (ton/ha) in the control plots to 9.38 (ton/ha) in the barely+ST and 9.96 (ton/ha) barely+ST+CZ plots. In the second year, its mean ranged from 3.69 (ton/ha) in the control plots to 4.95 (ton/ha) in the barely+ST+CZ plots and 5.20 (ton/ha) in the B+ ST plots, respectively (Table3).

In Mangali, the application of alternative farming system for two consecutive years had a significant effect on biological yield (p<0.05). In the first year, its biological yield ranged from 4.20 (ton/ha) in the control plots to 5.07 (ton/ha) in the barely+ST plots and 5.58 (ton/ha) in the barely+ST+CZ plots. In the second year, its mean ranged from 2.55 (ton/ha) in the control (mono-culture of barley) plots to 3.10 (ton/ha) in the barely+ST plots and 3.64 (ton/ha) in the barely+ST+CZ plots, respectively (Table3).

**Table 3.** Mean comparison of barley Yield components in two sites and two years

| Site | Treatments | Grain Yield (ton/ha) | | Straw Yield (ton/ha) | | Harvest Index (%) | | Barley biomass (ton/ha) | | Biological Yield (ton/ha) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Year1 | Year2 | Year1 | Year2 | Year1 | Year2 | Year1 | Year2 | Year1 | Year2 |
| Mangali | Barley (B) | 2.99 b | 1.19 b | 1.21 b | 1.36 b | 73 a | 47 a | 4.20 b | 2.55 b | 4.20 b | 2.55 b |
| | B+ST | 3.33 b | 1.15 b | 1.09 b | 1.29 b | 73 a | 47 a | 4.42 b | 2.44 b | 5.07 a | 3.10 a |
| | B+ST+CZ | 3.45 b | 1.52 b | 1.24 b | 1.74 b | 73 a | 47 a | 4.69 b | 3.26 a | 5.58 a | 3.64 a |
| Bandar Torkaman | Barley (B) | 3.37 b | 1.76ab | 2.87 a | 1.91 a | 54 b | 47 a | 6.25 a | 3.69 a | 6.25 b | 3.69 b |
| | B+ST | 4.12 a | 2.01 a | 3.12 a | 2.23 a | 57 b | 47 a | 7.25 a | 4.24 a | 9.38 a | 5.20 a |
| | B+ST+CZ | 4.18 a | 1.98 a | 3.13 a | 2.15 a | 57 b | 48 a | 7.31 a | 4.13 a | 9.96 a | 4.95 a |

Means of column with different letters have significant differences based on Tukey test (p< 0.05)
# B=barley, ST= *Salsola turcomanica,* CZ =*Chrysopogon zizanioides*

Means of location by year interactions for barley yield components and total biological yield in both sites over two years are presented in Table 4. In general, Bandar Torkaman had a significantly (p<0.05) higher barley yield component and biological yield than Mangali (Table 4). The mean of barley yield component and biological yield in two studied sites was higher in the first year as compared with the second year (Table 4).

**Table 4**. Mean comparison of Location by Year interactions for barley Yield components and Site Biological Yield in two sites and two years

| Site | Grain Yield (ton/ha) | | Straw Yield (ton/ha) | | Harvest Index (%) | | Barley biomass (ton/ha | | Biological Yield (ton/ha) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Year1 | Year2 | Year1 | Year2 | Year1 | Year2 | Year1 | Year2 | Year1 | Year2 |
| Mangali | 3.26 b | 1.29 b | 1.18 b | 1.47 b | 73.0 a | 47.0a | 4.44 b | 2.76 b | 5.06[b] | 3.11[b] |
| Bandar Torkaman | 3.89 a | 1.92 a | 3.04 a | 2.10 a | 56.0 b | 47.3a | 6.94 a | 4.02 a | 8.53[a] | 4.63 [a] |
| Mean | 3.58 | 1.61 | 2.10 | 1.78 | 64.5 | 47.0 | 5.69 | 3.39 | 6.80 | 3.87 |

Means of column with different letters have significant differences based on Tukey test ($p< 0.05$)

## Additional forage production

Additional forage production in two years in the study sites using ST+CZ species is presented in Table 5. *C. zizanioides* at the Mangali site was not successful for two consecutive years and all clones were withered. However, its forage production at Bandar Torkaman site was 0.031 (ton/ha) at the first year and 0.021 (ton/ha) at the second year, respectively (Table 3). The highest forage production of S. *turcomanica* was recorded at Bandar Torkaman site (2.623 ton/ha) in the first year and the lowest one (0.382 ton/ha) was recorded at Mangali site in the second year (Table 2).

**Table 5**. Additional forage production in two years in the study sites using new plant species (ton/ha)

| Site | Year | *Salsola turcomanica* (B+ST) | *Salsola turcomanica* (B+ST+CZ) | *Chrysopogon zizanioides* (B+ST+CZ) |
|---|---|---|---|---|
| Bandar Torkaman | Year1 | 2.133 ±0.270[b] | 2.623 ± 0.182[a] | 0.021± 0.005[c] |
| | Year2 | 0.957± 0.123[a] | 0.797± 0.193[b] | 0.031± 2.6[c] |
| Mangali | Year1 | 0.970 ± 0.268 [a] | 0.890 ± 0.376[a] | 0.00 [b] |
| | Year2 | 0.656 ± 0.238[a] | 0.382 ± 0.127 [a] | 0.00 [b] |

Means of column with different letters have significant differences based on Tukey test ($p< 0.05$)
# B=barley, ST= *Salsola turcomanica*, CZ =*Chrysopogon zizanioides*

## Discussion

In our study sites, like other ecosystems of the Mediterranean biome, most precipitation occurs during the cold seasons of the year. Moreover, annual precipitation and its seasonality are remarkably variable (Deitch *et al*., 2017). 10–year mean annual precipitation in these sites (Bandar Torkaman and Mangali) varies from 266 to 670 mm (151.8% variability) and 240 to 470 mm (95.8% variability), respectively. However, these sites (Bandar Torkaman and Mangali) receive more than 300 mm of precipitation annually (410 and 320 mm, respectively), specifying them from arid regions (Grove *et al*. 1977). The percentage of precipitation during summer in the Mediterranean biome varies from less than 5% to more than 20% (Deitch *et al*., 2017). According to the 10–year data, the mentioned precipitation for Bandar Torkaman and Mangali were 12.27% and 10.09%, respectively. In Bandar Torkaman, we observed that proportion of precipitation during summer was declined to less than half of the 10-year mean that is in accordance with Deitch *et al*. (2017) statement for some of Mediterranean-climate regions. Summer precipitation reduction can lead to enhanced stress on ecosystems and higher water demand for agriculture and municipalities.

*Salsola turcomanica* has a high potential for forage production and because of its high ash content can play an important role in the control of secondary salinity. The ash content of *S. turcomanica* is 35.6 % in the seed maturity stage (Arrekhi *et al*., 2021). Considering 0.89-2.62 ton/ha forage production of *S. turcomanica* in the first-year summer and 0.38-0.95 ton/ha in the second year, we can state that nearly 0.317 to 0.933 tom/ha and 0.136 to 0.34 ton/ha salts were removed from the soil of two study sites in two consecutive field trial. It has been reported that *Kochia scoparia* cultivation removes 200 to 300 kg/ha of soil salts in a year

(Salehi, 2012). Soil secondary salinization and the summer–autumn forage gap for livestock are the most general limitations of Australian ley farming system (Edwards *et al.*, 2019), so this alternative farming system can be a solution for these limitations. In addition, during summer and due to cultivation of *S. turcomanica*, wind erosion decreases with increasing soil surface roughness by *S. turcomanica* individuals. Moreover, in drought years, when barley production decreases, *S. turcomanica* can play more important roles in animal feeding and food security.

The significant effect of year indicated the significant difference in barley's yield components in each year. The significant effect of location likewise indicated the significant difference in barley's yield components in the two study areas. The significance of location×year interaction effect indicated differences in barley's yield components in different years and locations. According to the results, the effect of treatment on barley's yield components was not significant, thus it could be declared that our innovative cropping system has no negative effect on measured barley's yield components. No significant decline in the yield and yield components of barley was observed in the mixed cropping plots in two years and two locations. This makes it possible to introduce the optimal treatment for the study areas. The water requirement of barley for optimum yield is 390-430 mm (Alderfasi, 2009; Teulat *et al.*, 1997; Shone and Flood, 1988). Water shortage at each stage of crop growth can reduce yields with different intensities. Drought stress at flowering stage has a more negative effect on grain yield compared to early growth stages (Alderfasi, 2009 and Hasanpour *et al*., 2008). We observed that germination of *S. turcomanica* occurs at least one month after barley germination and it grows very slowly. It has been stated that at the time of barley harvest in late May, the height and root depth of *S. turcomanica* are not more than a few centimeters (Arrekhi *et al*., 2022). Effective root zone has been estimated as ~50 cm for barley (Fan *et al*., 2016), therefore small individuals of *S. turcomanica* do not compete with barley for water and nutrients during barley growth period. It must be mentioned that the depth of ground water is low in the study sites, therefore in addition to precipitation; the capillary flow during the summer seems to be effective in meeting the water requirement of *S. turcomanica*. *Salsola*, cultivation of the *C. zizanioides* was not successful in both study sites because its forage production was very negligible; therefore, its cultivation is not recommended in this region.

## Conclusion

Mixed cropping of barley and *Salsola turcomanica* is a feasible and cheap approach in order to produce more forage in semi-arid arable lands of Golestan province, Iran where has been to lack of forage for feeding the livestock. Application of this new cropping system did not affect the final yield of barley as a major crop in the region. Moreover, using this system provides plant cover for longer time on the soil which may have significant effects on soil physical and chemical properties and soil erosion in the region.

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# امکان سنجی اثرات الگوی کشت جایگزین بر محصول جو و تولید علوفه در منطقه نیمه خشک غرب استان گلستان، ایران

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**چکیده.** از چالش‌های عمده در مناطق نیمه خشک ایران تهیه علوفه برای دام‌ها و جلوگیری از تخریب مراتع به دلیل چرای زیاد دام است. در این تحقیق سه تیمار کشت مخلوط شامل جو خالص، جو مخلوط با سالسولا *Salsola turcomanica* و جو مخلوط با سالسولا و وتیور گراس *Chrysopogon zizanioides* از لحاظ تولید علوفه باهم مقایسه شدند. مطالعات مزرعه‌ای دو ساله از آذر ۱۳۹۷ تا مهر ۱۳۹۹ در دو سایت با استفاده از طرح بلوک‌های کامل تصادفی با چهار تکرار انجام شد. نتایج تجزیه واریانس مرکب بین دو سایت نشان داد که اثرات سال، مکان و اثر متقابل سال در مکان بر اجزای عملکرد محصول جو معنی‌دار بود (P<۰/۰۱). کشت مخلوط تاثیر منفی بر محصول دانه، محصول ساقه و شاخص برداشت جو نداشت. تیمارهای جو + سالسولا و جو+ سالسولا+ وتیورگراس در سال اول به دلیل عملکرد بالای سالسولا، توانستند ۲/۵ تن در هکتار علوفه بیشتر در مقایسه با سیستم تک کشتی جو تولید کنند. در هر دو سال، علوفه تولیدی سالسولا حدود ۲۵٪ کل بیوماس تولیدی بود. کاهش شدید بارندگی در سال دوم سبب کاهش محصول شد، بطوریکه تفاوت معنی‌داری بین سه سیستم زراعی در سال دوم یافت نشد. با اینحال، کشت مخلوط جو+سالسولا و جو+ سالسولا+ وتیور گراس توانستند حدود یک تن در هکتار علوفه بیشتری در مقایسه با سیستم تک کشتی جو تولید کنند. کشت مخلوط سالسولا و وتیور گراس با جو بر اجزای عملکرد نهایی جو تأثیری نداشت. در مجموع کشت مخلوط جو با سالسولا می‌تواند نه تنها پوشش گیاهی بر روی خاک را در طول سال تضمین کند بلکه برای تولید علوفه در مراتع در ایران توصیه می‌شود.

**کلمات کلیدی**: جو، سالسولا تورکمانیکا، وتیور گراس، کشت مخلوط