University of Birjand

Water Harvesting Research Vol. 6, No. 2, Autumn & Winter 2023, Original Paper p. 263-275

10.22077/JWHR.2024.7289.1128

The Effect of Plastic Mulch on Water Consumption and Morphophysiological Traits of Oat and Barley

Hassan Heidari[a*], Salman Aliakbari[b]

[a]Associate Professor, Department of Plant Production and Genetics Engineering, Faculty of Agricultural Science and Engineering, Razi University, Kermanshah, Iran.
[b]MSc Student, Department of Plant Production and Genetics Engineering, Faculty of Agricultural Science and Engineering, Razi University, Kermanshah, Iran.

[*]Corresponding Author, E-mail address: heidari1383@gmail.com
Received: 13 February 2024/ **Revised**: 22 March 2024/ **Accepted**: 25 March 2024

Abstract

Plastic mulches play an important role in reducing water consumption. An experiment was conducted at Research Greenhouse, Razi University, Iran. The experiment was a completely randomized design with three treatments and three replications. Plants used for testing were barley and oat. Treatments included control (without plastic mulch), transparent plastic mulch with half coverage and plastic mulch with almost full coverage. This study aimed at determining the percentage of the plastic cover that had the highest dry matter production and water use efficiency. Results showed that treatment of plastic mulch with almost full coverage had the lowest water consumption and the treatment without the plastic mulch had the highest water consumption. The treatment of barley with full coverage had a water-saving of almost 40 percent compared to control. Water use efficiencies for both plants treated with almost full coverage were highest among treatments. There was no significant difference between plastic mulch treatments in terms of leaf relative water content, fresh and dry weight of stem, fresh and dry weight of leaves, plant height, and leaf area in oat and barley. In this way, by applying a coating on the soil surface and preventing the loss of soil moisture, water consumption can be significantly reduced, while the dry matter produced is not reduced.

Keywords: Evapotranspiration, Forage crops, Irrigation, Soil coating, Water saving

1. Introduction

Food production systems around the world are vulnerable to water scarcity. Water scarcity causes a decrease in food production and financial loss (Sutcliffe et al., 2021). currently, water shortage is one of the major concerns of countries around the world. Climate change limits access to water by increasing temperature and decreasing precipitation, especially in mid-latitudes (Seneviratne et al., 2006). The arid and semi-arid regions of the world (approximately 44.7 million square kilometres) cover about 40% of the earth's surface and water scarcity is the main feature of these regions and drought is the most important stress on plants in these regions (Sloan et al., 1990). Water is the most important factor limiting crop production in arid and semi-arid regions of the world. Crops need a lot of water and lose huge amounts of it in the process of evapotranspiration (Xiang et al., 2020).

Plastic mulches have different colours depending on the type of application so that they are generally divided into three groups: dark, clear, and coloured. Bright mulches that are clear and white are especially important because of their greater light reflection. Mulches affect soil temperature (Jones et al., 2021; Wang et al., 2021). Mulches increase the water holding capacity of the soil by reducing evaporation and strengthening the soil aggregates. By maintaining soil moisture, plastic mulch causes the production of plant and animal biomass, which after death turn into organic matter to strengthen the soil aggregates. Some research has been done on the effects of various mulches on soil moisture retention (Campos-de-araujo et al., 1992; Ren et al., 2021; Zhu et al., 2021). The advantages of using plastic mulch are increasing water use efficiency, weed control, protecting soil from crusting, increasing soil fertility, preventing temperature fluctuations and moisture stresses, avoiding the accumulation of salts on the soil surface, protecting fruits from contact with wet soil, increasing crop maturity, increasing the green area of the field, protecting soil from erosion and increasing yield (Richard et al., 1987).

Due to the benefits of reducing water consumption and the high efficiency of the drip irrigation system, combining it with polyethylene mulch is effective in the optimal use of water (Yuan et al., 2019; Zhou et al., 2021). The use of plastic cover, in addition to being effective in weed control, reduces water consumption by preventing surface evaporation and thus reduces the number of irrigations. The use of mulch increased the efficiency of irrigation water and saved water by about 1500 cubic meters per hectare in cantaloupe. This is especially true in areas with arid and semi-arid climates where irrigation water supply is associated with difficulties (Jafari et al., 2007). Fereres and Goldhamer (1991) reported that the use of mulch in the early planting of cotton helps maintain soil moisture. Opara et al. (1992) reported that plastic coating treatment had a greater effect on soil moisture retention in dry periods than other mulches. Zolnoorian (1996) studied the effect of black plastic mulch on the ridge, black plastic mulch in the furrow, and control (without mulch) on tomato. Treatment of plastic mulch in the furrow with 79.6% increase in tomato yield, water-saving by 66.7%, and weed control by 70% compared to the control was the best treatment in Asadabad region. Rad (1999) investigated the effect of plastic and sand coating on the establishment of haloxylon and concluded that plastic coating can be effective in reducing evaporation and thus have a significant effect on increasing the establishment of haloxylon. This factor causes the restoration of clay plains as well as desert areas. Deng et al. (2006) reported that the use of plastic mulch is one of the ways to increase irrigation efficiency in semi-arid regions of China.

The results of a study showed that plastic mulch increased crop yield, improved water consumption and increased farmer's income. Although plastic mulch increased plant yield, it had little effect on evaporation and transpiration (Xiao et al., 2023). Plastic mulch, as a popular technique, leads to an increase in farmers' yield and income (Fu et al., 2021). Changes in soil conditions such as increasing soil temperature, reducing evaporation from the soil surface, reducing the loss of nutrients due to washing and reducing the growth of weeds are some of the effects of plastic mulch (Gao et al., 2019; Gu et al., 2020). Using plastic mulch for crop production and improving water consumption in some of the populous countries like China is significant (Sun et al., 2020). Plastic mulch had less evaporation and transpiration than straw mulch. Plastic mulch increased dry wheat grain yield and water use efficiency (Zhao et al., 2024).

In the study of the effect of plastic mulch cover in comparison with bare soil in water regimes on access to water and yield of papaya, it was seen that plastic mulch increased papaya yield in comparison with bare soil. Compared with bare soil, plastic mulch reduced the effect of irrigation regime on soil water availability (Coelho et al., 2022). Plastic mulch increased plant growth, yield, and water use efficiency of maize in two years compared to no plastic mulch (Fan et al., 2017). In the study of the effect of wheat straw mulch levels (0, 25%, 50%, 75%, and 100% of soil surface coverage) on soil moisture retention, it was observed that 75% and 100% coverage of wheat straw mulch had the highest soil moisture retention capacity (Rezaeipour et al., 2018). In a laboratory study of three levels of soil cover, including bare soil, low plant residue mulch cover (2 tons per hectare) and high plant residue mulch cover (4 tons per hectare), it was observed that the high mulch cover significantly increased soil moisture and reduced soil erosion (Montenegro et al., 2013). Plastic mulch increased seed yield in wheat (Qin et al., 2022), maize (Lee et al., 2021), and rice (Zhang et al., 2020).

Both barley and oat are fodder plants of the Poaceae family that have similar physiological characteristics. The foliage of both plants is used by livestock. One of the goals of this research was to evaluate the difference between these two plants in terms of reducing water consumption with the use of plastic mulch. So far, no comprehensive study has been done on fodder production under the conditions of using plastic mulch. In this research, the effect of plastic mulch on forage production and physiological and morphological characteristics of oat and barley have been investigated. The purpose of this experiment was to determine the percentage of plastic coating that had the highest dry matter production and water use efficiency.

2. Materials and Methods

This experiment was performed in the Research Greenhouse, Campus of Agriculture and Natural Resources, Razi University (Fig. 1). The experiment was a completely randomized design with three treatments and three replications. The plants used to test were barley and oat. The sowing date of both plants was 2016/11/7. Treatments included control (without plastic cover), transparent plastic mulch with half coverage, and plastic mulch with almost full coverage. Non-degradable plastic mulch was used in this research, but degradable plastics can be used in field conditions. It is possible to consider its collection and recycling, which, of course, requires relevant machinery and culture.

The experiment was performed in pots with a capacity of about 5 kg of soil and the pots were filled with farm soil (Table 1). The diameter and height of the pot were 18 cm and 20 cm, respectively. Irrigation for each treatment was equal to the water requirement and soil moisture retention at field capacity and the pots lacked drainage. The water consumption of two plants was not the same. Water consumption was based on the plant's water needs. Based on the demand of the plant, water was given to the pots. The water consumption of each plant and each pot was recorded during the whole period of water growth. Plastic mulch was applied immediately after germination.

Fig.1. Map of the studied area

Table 1. Physical and chemical properties of the soil

Soil texture	Soil pH	Electrical conductivity (ds/m)	Organic carbon (%)	Bulk density (g cm^{-3})	Field capacity (%)	Wilting point (%)
Silty clay	7.2	1.6	1.3	1.2	40	26

The choice of this stage was to study the reduction of evaporation from the beginning of plant growth. A transparent polyethylene cover was used to apply the treatments. For both barely and oat, six plants were preserved per pot and at the end; three plants per pot were harvested 60 days after planting to determine the plant characteristics and final yield.

The pots were irrigated according to the appearance and freshness of plants and the dryness of the soil (Sivapalan, 2006; Heidari et al., 2011). The pots were irrigated before germination at five stages with an average irrigation interval of 4 days.

After germination and during the application of treatments in treatments with plastic cover due to less evaporation, the irrigation interval was longer. The treatments were irrigated manually by a 5 litre watering can. In each watering, a certain amount of water was given to each pot so that they are completely wet, but no moisture is drained from the pot. The treatments were applied for 60 days and then plants were harvested as forage to determine biomass.

The measured traits included plant height, leaf number per plant, stem fresh weight, leaf fresh weight, stem dry weight, leaf dry weight, leaf relative water content, leaf area, water consumption, and water use efficiency for each plant. The height of the plant was measured with a ruler with an accuracy of one millimetre. Only completely open leaves were used in counting the number of leaves. Plants were weighed to estimate the initial fresh weight immediately after harvest.

To determine the dry weight of leaves and stems, the plants were kept in an oven at 75 ° C for 24 hours and then weighed. The leaf area was obtained by multiplying the leaf length by the leaf width and multiplying it by 0.75 (Heidari et al., 2019). The water consumption during the entire growth period of the plant was calculated cumulatively for each pot by means of a graduated cylinder, and it was considered as the water consumption of that plot.

To calculate the leaf relative water content 57 days after sowing, samples were taken from three plants per pot and the terminal leaves of each plant were removed with scissors. The last developed leaf without breaks and tears was used. After measuring the leaf fresh weight (FW), the leaf was placed in distilled water for 24 hours and then the leaf turgid weight (TW) was calculated.

Finally, the leaves were dried in an oven for 24 hours and the leaf dry weight (DW) was calculated and the leaf relative water content (RWC) was obtained based on the following Eq.1 (Ritchie et al., 1990; Heidari et al., 2017).

$$RWC = (FW-DW)/ (TW-DW) \quad (1)$$

Water use efficiency was obtained by dividing the dry matter produced by the plant by the amount of water consumed per plant. Before analyzing the data, their normality was checked by Minitab software (ver. 11.12). SAS software (ver. 9.2) was used to analyze the variance of treatments. LSD test at 5% probability level was used to compare the mean of treatments. Excel software was used to draw the figures.

3. Results and Discussion

3.1. Water consumption and water use efficiency

Analysis of variance showed that plastic mulch had a significant effect on water consumption and water use efficiency in barley and oat plants (Table 2).

Fig. 2 shows water consumption equation for effect of plastic mulch on water consumption in barley (Fig. 2a) and oat (Fig. 2b). A comparison of mean data in both oat and barley showed that the treatment of plastic mulch with almost full coverage had the lowest water consumption and the highest water consumption was related to the treatment without plastic coating (Fig. 3a and 4a).

In other words, applying plastic mulch on plants significantly prevented water wastage. Burt et al. (2002) showed that the use of mulch and straw on the soil can reduce the rate of evaporation from the soil surface after irrigation from 11% to 84% for a short period and a half in the long term. In soil with a plastic coating, water vapour pressure under the plastic layer probably increases, and this factor, along with the lack of effect of wind flow on water vapour, can play a significant role in reducing evaporation from the soil.

Zhang and Sun (2007) also reported that the use of straw mulch in a wheat field reduced the evaporation rate from the soil surface by 19% compared to the control treatment. Increased soil moisture in the presence of mulch has been reported by Rahman et al. (2005) and Bilalis et al. (2003).

The mean comparisons showed that in oat plants, plastic mulch with almost full coverage was superior to the other two treatments in terms of water use efficiency. But plastic mulch with half coverage compared to the control treatment was not significantly different in terms of water use efficiency. In barley, plastic mulch with full cover had higher water use efficiency than the control, but no significant difference in terms of water use efficiency was observed between complete soil cover and half soil cover (Fig. 3b and 4b). Chakraborty et al. (2008) in an experiment concluded that mulch from rice residues in limited irrigation conditions was able to retain soil moisture and plant water, which resulted in higher water use efficiency and higher yield in wheat.

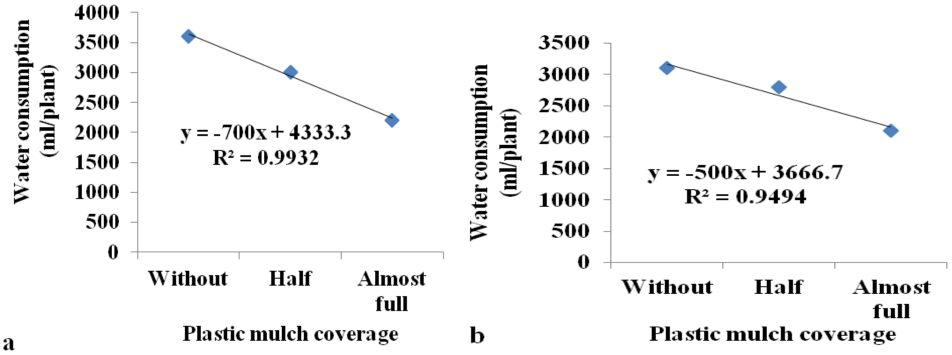

Fig. 2. Water consumption equation for effect of plastic mulch on water consumption in barley (a) and oat (b).

Table 2. Analysis of variance (mean square) of effect of plastic mulch on water consumption and morphophysiological traits in oat and barley

Plant	Sources of variation	Degree of freedom	Water consumption	Water use efficiency	Total dry matter	Leaf relative water content	Stem dry weight	Leaf dry weight	Leaf fresh weight	Stem fresh weight	Leaf number per plant	Plant height	Leaf area
Barley	Treatment	2	1480000**	0.02*	0.11ns	8.77ns	0.004ns	0.07ns	0.56ns	0.18ns	22.95ns	8.34ns	1.63ns
	Error	6	0.000	0.01	0.09	4.99	0.020	0.02	0.39	0.43	20.58	4.73	0.77
Oat	Treatment	2	790000**	0.043**	0.02ns	0.11ns	0.004ns	0.01ns	0.18ns	0.31ns	0.5ns	2.1ns	10.1ns
	Error	6	0.000	0.002	0.02	4.11	0.002	0.01	0.35	0.21	1.5	6.0	17.9

**and*: Significance at the 1% and 5% probability level, respectively. ns: no significant

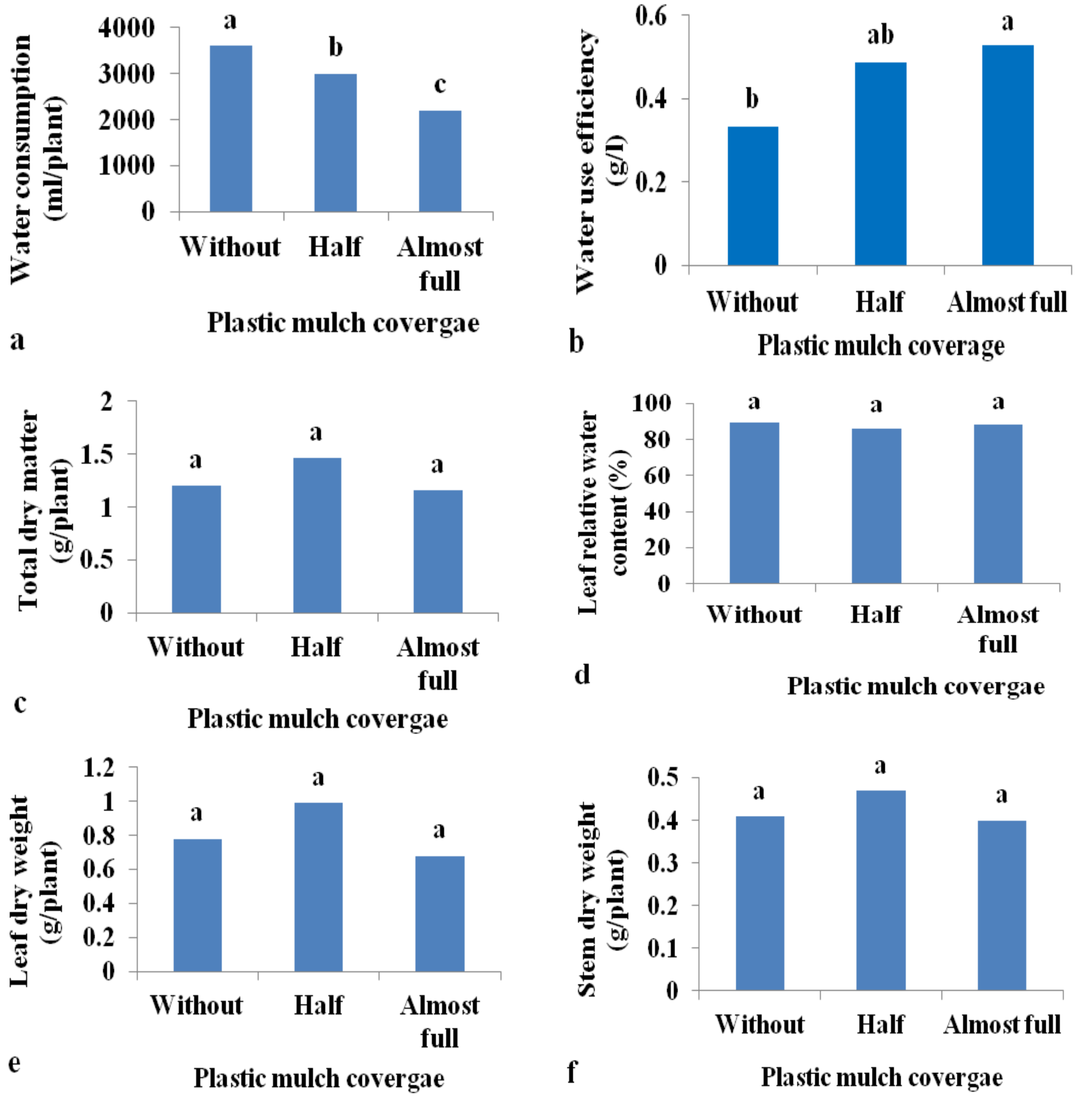

Fig. 3. Mean comparison for effect of plastic mulch on water consumption (a), water use efficiency (b), total dry matter (c), leaf relative water content (d), leaf dry weight (e), and stem dry weight (f) in barley. Means with the same letter are not significantly different according to Duncan’s test.

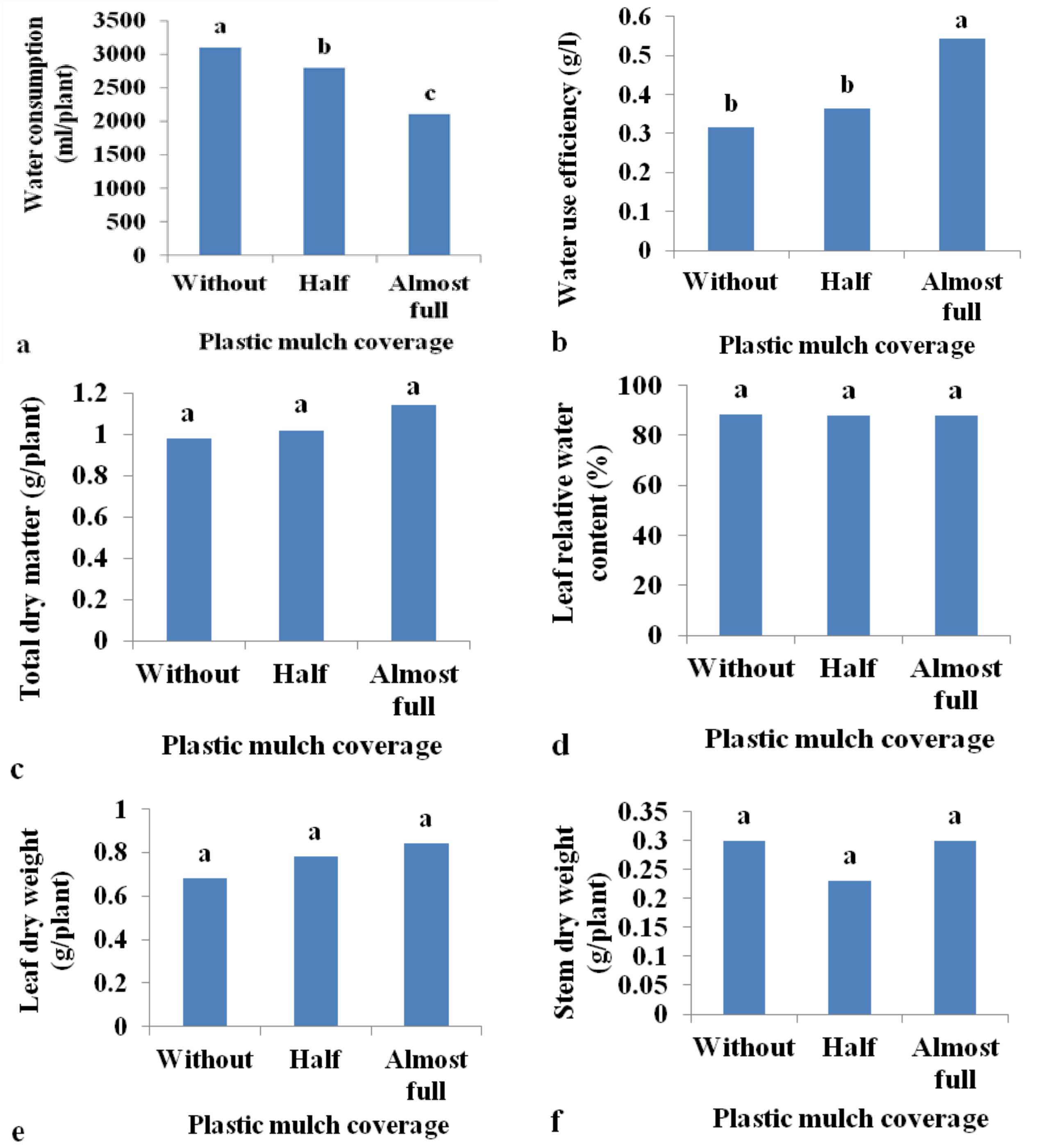

Fig. 4. Mean comparison for effect of plastic mulch on water consumption (a), water use efficiency (b), total dry matter (c), leaf relative water content (d), leaf dry weight (e), and stem dry weight (f) in oat. Means with the same letter are not significantly different according to Duncan's test.

3.2. Total dry matter, morphological, and physiological characteristics

Analysis of variance showed that plastic mulch had no significant effect on total dry matter, leaf relative water content, leaf dry weight, stem dry weight, leaf fresh weight, stem fresh weight, leaf number per plant, plant height, and leaf area in both barley and oat plants (Table 2).

All treatments were in the same environmental conditions. Despite the much higher water consumption in the control treatment and also in the treatment of plastic mulch with half coverage compared to the treatment of plastic mulch with almost full coverage, there was no significant difference in the total dry matter production in oat and barley (Fig. 3c and 4c). This shows the complete superiority of plastic mulch with almost full coverage due to the reduction of the contact surface of wet soil with the open air and the reduction of evaporation. It seems that if the water consumption of the control treatment was less than the amount used in this experiment, the total dry matter in the plastic-coated treatments could be significantly higher than the control treatment. It is due to that water consumption for control treatment is much higher than complete nylon cover treatment to produce equal dry matter. Water consumption for barley in the treatment with full plastic cover was about 40% less than the control treatment. Therefore, in this experiment, the focus was more on less water consumption and increasing water use efficiency. Water consumption in barley control treatment was higher than the oat control treatment, which indicates that barley consumed more water during the growing season. It seems that if the control treatment was irrigated with less water per time, it could cause a significant difference in dry matter production in both plants, while the amount of water consumption was still significant. In rice (*Oryza sativa* L.), plastic mulch had a similar seed yield to non-mulch treatment, but in plastic mulch treatment, water consumption decreased and water productivity increased, which is consistent with the results of the present study (Liu et al., 2021). Mirzaolian et al. (2000) stated that the use of polyethylene mulch can significantly increase the yield by changing the irrigation interval from seven to 14 days in cantaloupe while saving water consumption. Increased yield in the mulch system can be the result of maintaining sufficient moisture, which increases microbial activity and increases nutrient mobility (Dahiya et al., 2007).

The results showed that there was no significant difference between plastic mulch treatments in terms of leaf relative water content (Fig. 3d and 4d) in oat and barley. It should be noted that although much less water was used in treatments of plastic mulch with half coverage and almost full coverage, they did not have a significant difference in the leaf relative water content compared to the control. This shows the significant effect of plastic coating on plant water retention during the growing season. The lack of difference between plastic mulch treatments in terms of leaf relative water content shows that plastic mulch is able to maintain leaf relative water content by maintaining soil moisture in conditions of less water consumption. When the leaf is in a suitable level in terms of water, cellular turgescence leads to the maintenance of photosynthesis and biomass production. In an experiment reported by Kamsari et al. (2013), Mazut mulch increased plant height, leaf number, leaf relative water content, fresh forage yield, and decreased tiller number, proline content, and sugar content under stress conditions in millet. The effect of mulch on faster plant establishment seems to be the reason for these results.

There was no significant difference between plastic mulch treatments in terms of leaf dry weight (Fig. 3e and 4e), stem dry weight (Fig. 3f and 4f), leaf fresh weight (Fig. 5a and 6a), and stem fresh weight (Fig. 5b and 6b) in oat and barley. The lack of difference in the dry and fresh weight of the stems and leaves of the two plants in the conditions that less water was consumed can be attributed to the positive effect of plastic mulch in reducing evaporation and maintaining soil moisture, which can also be seen through maintaining moisture in the leaves. In the study of the effect of plastic mulch on thyme (*Thymus daenensis*) yield, it was observed that mulch had a significant effect on dry weight, plant diameter, and plant height. Plastic mulch increased the yield of dry matter and plant essential oil (Najafi Ashtiani et al., 2011).

There was no significant difference between plastic mulch treatments in terms of leaf number per plant (Fig. 5c and 6c) and plant height (Fig. 5d and 6d) in oat and barley. Maintaining moisture by mulch provides the conditions for improving plant growth characteristics such as plant height and number of leaves. In the study of the effect of water salinity and types of mulch on the morphological characteristics of maize, it was seen that plastic mulch had a positive effect on the height of the plant (139.7 cm) and the number of leaves (10.33) of maize (Bayat et al., 2019).

There was no significant difference between plastic mulch treatments in terms of leaf area (Fig. 5e and 6e) in oat and barley. Reduction of the leaf area is one of the morphological responses of the plant to drought, because the leaves reduce the moisture reserve of the soil by transpiration losses. The lack of reduction in the leaf area in the plastic mulch treatment, despite the reduction in water consumption, can be seen as a sign of proper moisture storage in the soil. In the study of the effect of magnetic water and transparent plastic mulch on the leaf area of green beans, it was seen that the combined use of magnetic water and plastic mulch increased the leaf area by 5.13% compared to the control (Nikbakht et al., 2022).

Hosseini and Nemati (2014) reported that plastic mulch treatment and irrigation interval had a significant effect on reproductive traits such as number of flowers, number of fruits, and fruit weight, but had no significant effect on plant height. In the early stages of growth, the presence of moisture around the roots of the plant in cultivation with mulch led to an increase in the number of flowers compared to the cultivation without mulch. The low water requirement of the plant due to the lower expansion of the plant can be considered a possible reason for the increase in the number of flowers per plant despite the decrease in the number of irrigation applications.

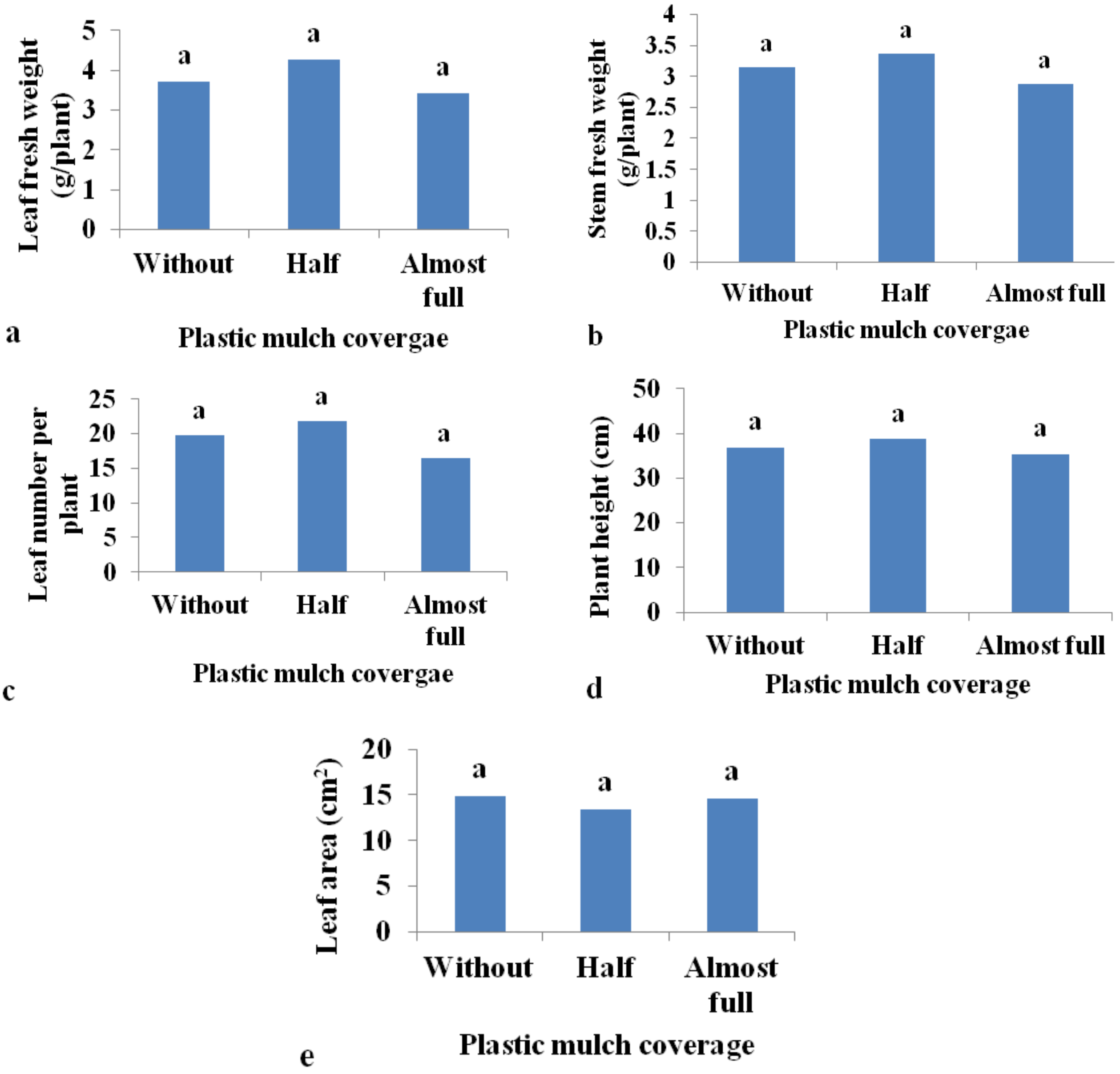

Fig. 5. Mean comparison for effect of plastic mulch on leaf fresh weight (a), stem fresh weight (b), leaf number per plant (c), plant height (d), and leaf area (e) in barley. Means with the same letter are not significantly different according to Duncan’s test.

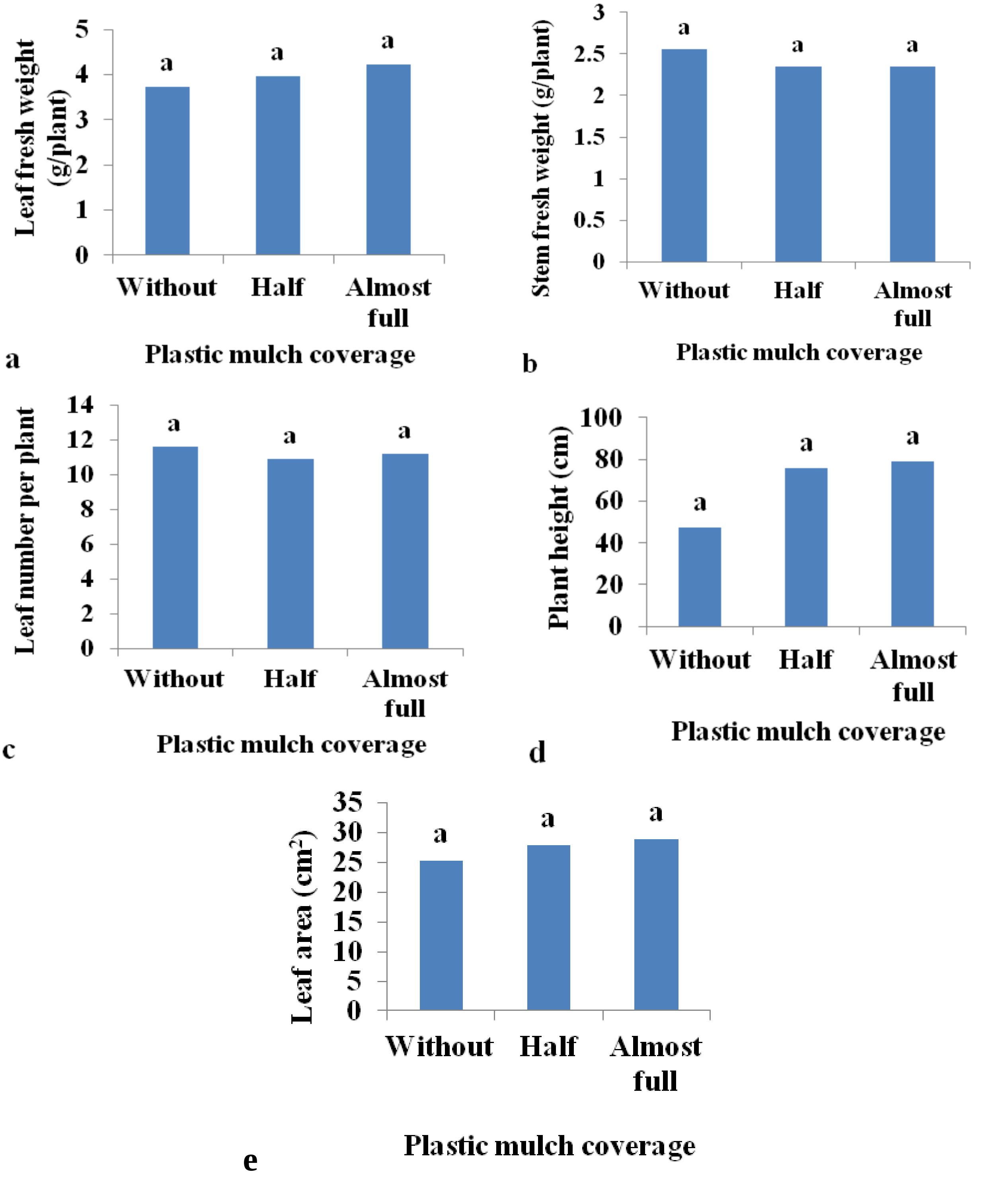

Fig. 6. Mean comparison for effect of plastic mulch on leaf fresh weight (a), stem fresh weight (b), leaf number per plant (c), plant height (d), and leaf area (e) in oat. Means with the same letter are not significantly different according to Duncan's test.

4. Conclusion

The results of this experiment in general showed that the treatment with almost full plastic coating had the greatest effect on maintaining soil moisture. By applying a coating on the soil surface and preventing the loss of soil moisture, water consumption can be significantly reduced, while the dry matter produced is not reduced. By applying mulch, it is possible to minimize production costs, a large part of which is related to the water supply to the plant, without reducing production. Less water consumption reduces environmental degradation. In this way, the available water is used optimally and the area under cultivation of crops is increased by saving water. Despite the limited water resources, more crops can be harvested than conventional cultivation. It is recommended to use dark plastic mulch to investigate the effect of mulch colour on crops at the next experiments. In addition, in future research, the amount of irrigation water for treatment with plastic mulch can be considered less than treatment without plastic mulch.

5. Disclosure statement

No potential conflict of interest was reported by the authors

6. References

Bayat, Z., Sadeghipour, A., Yazdani, M.R., & Zulfiqari, A.A. (2019). Fodder production and morphological characteristics of fodder corn (*Zea mays* L.) at different levels of water salinity and types of mulch. *Pasture*, *14*(2), 248-271. https://sid.ir/paper/523964/fa

Bilalis, D., Sidiras, N., Economou, A., & Vakali, C. (2003). Effect of different levels of wheat straw soil surface coverage on weed flora in *Vicia faba* crops. *Journal of Agronomy and* Crop Science, 189, 233-241. https://doi.org/10.1046/j.1439-037X.2003.00029.x

Burt, C. M., Mutziger, A., Howes, D. J., & Solomon, K.H. (2002). The effect of stubble and mulch on soil evaporation. Irrigation training and research center, BioResource and Agricultural Engineering Department, California Polytechnic State University San Luisobis. CA 93407-805-756-2433.

Campos-de-araujo, J.A., & Campos-de-araujo, S.M. (1992). Analysis of cucumber (*Cucumis sativus* L.) production "Vista Alegre" variety, using different coloured plastic soil mulch. In *Congreso International De Plasticos Enagricultura*, pp.108-113.

Chakraborty, D., Nagarajan, S., Gupta, V., & Tomar, R. (2008). Effect of mulching on soil and plant water status, and the growth and yield of wheat (*Triticum aestivum* L.) in a semi-arid environment. *Agricultural Water Management*, 95, 1323-1334. https://doi.org/10.1016/j.agwat.2008.06.001

Coelho, E.F., Santos, D.L., Lima, L.W.F.d., Castricini, A., Barros, D.L., Filgueiras, R., & da Cunha, F.F. (2022). Water regimes on soil covered with plastic film mulch and relationships with soil water availability, yield, and water use efficiency of papaya trees. *Agricultural Water Management*, *269*, 107709. https://doi.org/10.1016/ j.agwat.2022.107709.

Dahiya, R., Ingwersen, J., & Streck, T. (2007). The effect of mulching and tillage on the water and temperature regimes of a loess soil: experimental findings and modeling. *Soil and Tillage Research*, *96*(1-2), 52-63. https://doi.org/10.1016/j.still.2007.02.004

Deng, X.P., Shan, L., Zhang, H., & Turner, N.C. (2006). Improving agricultural water use efficiency in arid and semiarid areas of China. *Agricultural Water Management*, *80*(1-3), 23-40. https://doi.org/10.1016/j.agwat.2005.07.021

Fan, Y., Ding, R., Kang, S., Hao, X., Du, T., Tong, L., & Li, S. (2017). Plastic mulch decreases available energy and evapotranspiration and improves yield and water use efficiency in an irrigated maize cropland. *Agricultural Water Management*, *179*, 122-131. https://doi.org/10.1016/j.agwat.2016.08.019.

Fereres E., & Goldhamer D.A. (1991). Plastic mulch increases cotton yield, reduces need for preseason irrigation. *California Agriculture*, *45*(3), 25-28. doi.org/10.3733/ca.v045n03p25

Fu, W., Fan, J., Hao, M., Hu, J., & Wang, H. (2021). Evaluating the effects of plastic film mulching patterns on cultivation of winter wheat in a dryland cropping system on the Loess Plateau, China. *Agricultural Water Management*, *244*, 106550.

Gao, H., Yan, C., Liu, Q., Ding, W., Chen, B., & Li, Z. (2019). Effects of plastic mulching and plastic residue on agricultural production: a meta-analysis. *Science of the Total Environment*, *651*, 484-492.

Gu, X., Cai, H., Fang, H., Li, Y., Chen, P., & Li, Y. (2020). Effects of degradable film mulching on crop yield and water use e fficiency in China: a meta-analysis. *Soil Research*, *202*, 104676.

Heidari, H., Jahansooz, M.R., Yunusa, I., Hosseini, S.M.B., Chaichi, M.R., & Jafari, A.A. (2011). Effect of alternate irrigation on root-divided foxtail millet (*Setaria italica*). *Australian Journal of Crop Science*, *5*(2), 205-213.

Heidari, H., Yosefi, M., Sasani, S., & Nosratti, I. (2019). Effect of irrigation with detergent-containing water on foxtail millet shoot biomass and ion accumulation. *Environmental Science and Pollution Research*, *26*, 6328-6335. https://doi.org/10.1007/s11356-018-3966-y

Heidari, H., Yosefi, M., Sasani, Sh., & Nosratti, I. (2017). Effect of contaminated water with laundry detergent on foxtail millet root and physiological traits. *Tenside Surfactants Detergents*, *54* (2), 118-124. https://doi.org/10.3139/113.110487

Hosseini, A., & Nemati, H. (2014). The effect of irrigation interval on growth characteristics, quantitative and qualitative yield of tomatoes in the conditions of application and non-application of plastic mulch. *Journal of Agroecology*, *6*, 552-560.

Jafari, P., Mollahosaini, H., & Silspoor, M. (2007). Investigation effect of cantaloupe planting pattern in two methods of traditional and use mulch. *Journal of Research in Agricultural Science*, *2*(2), 61-71.

Jones, H., Black, T.A., Jassal, R.S., Nesic, Z., Johnson, M.S., & Smukler, S. (2021). Characterization of shortwave and longwave properties of several plastic film mulches and their impact on the surface energy balance and soil temperature. *Solar Energy*, *214*, 457-470. https://doi.org/10.1016/j.solener.2020.11.058

Kamsari, S., Khajouinejad, Gh., & Farahbakhsh, H. (2013). Effect of antiperspirants and mulch on water use efficiency and yield of millet (*Pennisetum americanum*, cv. nutrifeed) under drought stress conditions. In *12th National Conference on Irrigation and Evaporation Reduction, Shahid Bahonar University of Kerman, Kerman, Iran.*

Lee, J.G., Chae, H.G., Hwang, H.Y., Kim, P.J., & Cho, S.R. (2021). Effect of plastic film mulching on maize productivity and nitrogen use efficiency under organic farming in South Korea. *Science of The Total Environment*, *787*, 147503. https://doi.org/10.1016/j.scitotenv.2021.147503

Liu, J., Huang, X., Jiang, H., & Chen, H. (2021, August). Sustaining yield and mitigating methane emissions from rice production with plastic film mulching technique. *Agricultural Water Management*, 245, 106667. https://doi.org/10.1016/j.agwat.2020.106667

Mirzaolian, A., Kashi, A., & Sohrabi, T. (2000). Evaluation of irrigation regime and dark polyethylene sheet effects on growth and yield of cantaloupe. In *the second Congress of Iranian Horticultural Science, 23 August, Karaj, Tehran, Iran*, 437 pp.

Montenegro, A.A.A., Abrantes, J.R.C.B., de Lima, J.L.M.P., Singh, V.P., & Santos, T.E.M. (2013). Impact of mulching on soil and water dynamics under intermittent simulated rainfall. *CATENA*, *109*,139-149. https://doi.org/10.1016 /j.catena.2013.03.018.

Najafi Ashtiani, A., Sefidkan, F., & Baschi, M. H. (2011). Investigating the effects of plastic mulches on the yield of the medicinal plant Thymus daenensis in dry conditions. In *National Conference of Medicinal Plants*. https://sid.ir/paper/820954/fa

Nikbakht, J., Mohammadi, F., & Barzegar, T. (2022). Effect of magnetic irrigation water and transparent plastic mulch on yield and water use efficiency in green beans cv. Alamout. *Iranian Journal of Irrigation and Drainage*, *16*(3), 550-562. https://sid.ir/paper/1054109/en

Opara, O., Salau, O., & Swennen, R. (1992). Response of plantain to mulch on a tropical ultisol: Part II. Effect of different mulching materials on soil hydrological properties. *International Agrophysics*, *6*, 3-4.

Qin, Y., Chai, Y., Li, R., Li, Y., Ma, J., Cheng, H., Chang, L., & Chai, S. (2022). Evaluation of straw and plastic film mulching on wheat production: A meta-analysis in Loess Plateau of China. *Field Crops Research*, *275*, 108333. https://doi.org/10.1016/j.fcr.2021.108333

Rad, M. H. (1999). Effect of mulch materials on establishment and growing of haloxylon. In *Proceeding of seventh national seminar on irrigation and evapotranspiration. University of Shahid Bahonar, Kerman, Iran*, pp. 460-469.

Rahman, A.M., Chikushi, J., Saifizzaman, M., & Lauren, J.G. (2005). Rice straw mulching and nitrogen response of no-till wheat following rice in Bangladesh. *Field Crops Research*, *91*(1), 71-81. https://doi.org/10.1016/j.fcr.2004.06.010

Ren, A.-T., Zhou, R., Mo, F., Liu, S.-T., Li, J.-Y., Chen, Y., Zhao, L., & Xiong, Y.-C. (2021). Soil water balance dynamics under plastic mulching in dryland rainfed agroecosystem across the Loess Plateau. *Agriculture, Ecosystems & Environment*, *312*, 107354. https://doi.org/10.1016/j.agee.2021.107354

Rezaeipour, Z., Vaezi, A. R., & Baba akbari, M. (2018). Investigating the effect of wheat straw mulch on soil water retension in rainfed condition. *Iranian Journal of Soil and Water Research, 49*(5), 955-964. https://doi.org/10.22059/ijswr .2018.219065.667560

Richard, D., Bonannno, A., William, J., & Lamont, J.R. (1987). Effect of polyethylene mulches, Irrigation method and row covers on soil and air temperature and yield of muskmelon. *Journal of the American Society of Horticultural Science*, *112* (5), 735-738.

Ritchie, S.W., Nguyen, H.T., & Holaday, A.S. (1990). Leaf water content and gas-exchange parameters of two wheat genotypes differing in drought resistance. *Crop Science*, *30*, 105-111. https://doi.org/10.2135/cropsci1990.0011183X00 3000010025x

Seneviratne, S.I., Luthi, D., Litschi, M., & Schar, C. (2006). Land- atmosphere coupling and climate change in Europe. *Nature*, *443*, 205-209. https://doi.org/10.1038/nature05095

Sivapalan, S. (2006). Some benefits of treating a sandy soil with a cross-linked type polyacrylamide. *Australian Journal of Experimental Agriculture*, *46*, 579-584.

Sloan, R.J., Patterson, R.P., & Carter, T.E. (1990). Field drought tolerance of soybean plant introduction. *Crop Science*, *30*, 118-123.

https://doi.org/10.2135/cropsci1990.0011183X003000010027x

Sun, D., Li, H., Wang, E., He, W., Hao, W., Yan, C., Li, Y., Mei, X., Zhang, Y., & Sun, Z. (2020). An overview of the use of plastic-film mulching in China to increase crop yield and water-use efficiency. *National Science Review*, *7*, 1523-1526. https://doi.org/10.1093/nsr/nwaa146

Sutcliffe, C., Knox J., & Hess T. (2021). Managing irrigation under pressure: How supply chain demands and environmental objectives drive imbalance in agricultural resilience to water shortages. *Agricultural Water Management*, *243*, 106484. doi.org/10.1016/j.agwat.2020.106484.

Wang, Z., Li, M., Flury, M., Schaeffer, S.M., Chang, Y., Tao, Z., Jia, Z., Li, S., Ding, F., & Wang, J. (2021). Agronomic performance of polyethylene and biodegradable plastic film mulches in a maize cropping system in a humid continental climate. *Science of The Total Environment*, *786*, 147460. https://doi.org/10.1016/j.scitotenv.2021.147460

Xiang, K., Li, Y., Horton, R., & Feng, H. (2020). Similarity and difference of potential evapotranspiration and reference crop evapotranspiration – a review. *Agricultural Water Management*, *232*, 106043. https://doi.org/10.1016/j.agwat.2020.106043

Xiao, L., Wei, X., Wang, C., & Zhao, R. (2023). Plastic film mulching significantly boosts crop production and water use efficiency but not evapotranspiration in China. *Agricultural Water Management*, *275*,108023. https://doi.org/ 10.1016/ j.agwat.2022.108023.

Yuan, X., Bai, J., Li, L., Kurban, A., & De Maeyer, P. (2019). Modeling the effects of drip irrigation under plastic mulch on vapor and energy fluxes in oasis agroecosystems, Xinjiang, China. *Agricultural and Forest Meteorology*, *265*, 435-442. https://doi.org/10.1016/j.agrformet.2018.11.028

Zhang, C., & Sun, P. (2007). Effects of straw mulching on soil temperature, evaporation and yield of winter wheat: field experiments on the North China Plain. *Annals of Applied Biology*, *150*(3), 261-268. https://doi.org/10.1111/j.1744-7348.2007.00144.x

Zhang, G., Yang, Y., Huang, Q., Ma, J., Yu, H., Song, K., Dong, Y., Lv, S., & Xu, H. (2020). Reducing yield-scaled global warming potential and water use by rice plastic film mulching in a winter flooded paddy field. *European Journal of Agronomy*, *114*, 126007. https://doi.org/10.1016/j.eja.2020.126007

Zhao, H., Liu, G., Dou, Y., Yang, H., Wang, T., Wang, Z., Malhi, S., & Khan, A.A. (2024). Plastic mulch increases dryland wheat yield and water-use productivity, while straw mulch increases soil water storage. *Journal of Integrative Agriculture*. doi.org/10.1016/j.jia.2024.01.008.

Zhou, L., Feng, H., & Zhao, W. (2021). Plastic film mulching affects the critical nitrogen dilution curve of drip-irrigated maize. *Field Crops Research*, *263*, 108055. https://doi.org/10.1016/ j.fcr.2021.108055

Zhu, G., Yong, L., Zhang, Z., Sun, Z., Wan, Q., Xu, Y., Ma, H., Sang, L., Liu, Y., Wang, L., Zhao, K., & Guo, H. (2021). Effects of plastic mulch on soil water migration in arid oasis farmland: Evidence of stable isotopes. *CATENA*, *207*, 105580. https://doi.org/10.1016/j.catena.2021.105580

Zolnoorian, H. (1996). Investigation of the effects of dark plastic mulch on the cultivation of tomato cultivars. M.Sc. Thesis, Islamic Azad University of Karaj.