Water Harvesting Research Vol. 6, No. 1, Spring & Summer 2023, Original Paper p. 88-96
University of Birjand
10.22077/JWHR.2023.6835.1110

Effects of Evapotranspiration Reduction on Rice; Towards a Closed Water System

Hassan Heidari[a*], Fatemeh Jamali[a]
[a]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: 29 September 2023/ **Revised**: 25 October 2023/ **Accepted**: 18 November 2023

Abstract

Drought is an abiotic stress that limits global rice production. Plastic mulch is one of the ways to reduce water consumption. To evaluate the closed water system in the pot, a study was conducted to determine the level of reduction of evapotranspiration that did not have an adverse effect on the vegetative growth of rice. Experimental treatments included: Treatment 1: 100 % control of evapotranspiration (The lid of the pot was always closed), Treatment 2: The pot lid was closed and the lid was left open for one hour every day. Treatment 3: The pot lid was closed and the lid was left open for one hour every two days, Treatment 4: The pot lid was closed and the lid was left open for one hour every three days, Treatment 5 (control): No control of evapotranspiration (pot lid was always open). Results showed that the control treatment (no control of evapotranspiration) had the lowest plant height, stem diameter, number of leaves per plant, leaf area, leaf relative water content, root volume, root weight, leaf fresh weight, leaf dry weight, and water use efficiency compared to the evapotranspiration control treatments. 100 % control of evapotranspiration had the lowest water consumption. In closed pots, due to the high relative humidity of the air inside the pot, the tendency of water molecules to convert from liquid to vapor decreases. Overall, the results of this study showed that it is possible to plant crops such as rice in a closed environment in terms of humidity.
Keywords: Air relative humidity, Root, Water deficit stress, Water harvesting, Water saving.

1. Introduction

Rice (*Oryza sativa* L.) is an important human food source worldwide. Many efforts have been made to maintain the yield of this plant (Sibo et al., 2021). Rice fields have high evapotranspiration due to flood cultivation. Evapotranspiration (ET) refers to the total water lost from evaporation through the plant growth medium and transpiration from plant surfaces (Wang et al., 2021). Among the factors controlling evapotranspiration in wheat and maize fields, it was found that net radiation and surface conductance directly controlled evapotranspiration, but the vapor pressure deficit indirectly controlled evapotranspiration through surface conductance (Wang et al., 2022).

Various ways to reduce evapotranspiration in rice have been studied. One of these solutions is to use mulches. Plastic mulch is one of the most effective mulches in reducing evapotranspiration. The effect of pruning wastes as organic mulching and plastic mulching on evapotranspiration of vineyards in a semi-arid climate was investigated. The results showed that organic and plastic mulch reduced the evapotranspiration of the vineyard. Different soil management methods did not affect vine transpiration. Organic mulch can reduce water shortages under drought conditions (López-Urrea et al., 2020). Three patterns of film mulching (flat planting without mulching (FPNM)), ridge-furrow with biodegradable film mulch on the ridge (RFBM), and ridge-furrow with plastic film mulch on the ridge (RFPM) were examined in a maize field. Both RFBM and RFPM reduced evaporation, evapotranspiration, and evapotranspiration to evapotranspiration ratio compared to FPNM, and increased yield and water use efficiency (Fang et al., 2021). The use of plastic mulch compared with not using plastic mulch in rice increased grain yield by 20 %, water use efficiency by 106.0 %, and irrigation water use efficiency by 519.6 % (Li et al., 2007). Plastic mulch reduced thrips damage and delayed virus outbreaks in hot pepper (*Capsicum* spp.). The positive effect of plastic mulch on the health of hot pepper led to improved crop production (Vos et al., 1995). The plastic film mulch in different colors had a maize grain yield increase of 78 % to 149 % over control. The white plastic mulch treatment had a 2 °C higher temperature than the control treatment. The black plastic mulch had a 0.2 °C lower temperature than the control (Haque et al., 2018). Plastic mulch in maize resulted in increased yield, net profit, and cost-benefit ratio. Plastic mulch increased global warming potential, but reduced greenhouse gas emissions. Areas with less than 500 mm of rainfall are prone to the use of plastic mulch (Zhang et al., 2021b).

Plastic mulching led to higher growth and higher yield than non-mulch treatments in chili pepper production in semi-arid environments with sandy loam soils. Increased crop yield and growth were due to suitable soil temperature and moisture conditions (Adekaldu et al., 2021).

The application of two types of plastic and straw mulch in a wheat field was compared. It was observed that straw strip mulching was slightly different from plastic mulch in terms of grain yield, straw yield, and soil moisture storage. Because straw mulch is cheaper and more environmentally friendly, the use of this treatment is recommended (Chai et al., 2021).

In autumn and winter, yellow and silver plastic mulches increased the growth of tomato plants. In autumn and winter cultivation, green and silver plastic coatings increased the yield and number of fruits. Therefore, depending on the growing season, mulch has certain effects on plant growth and tomato yield (Mendonça et al., 2021).

The Watergy project includes a humid air solar system that follows the principle of a closed two-phase thermosyphon. The combination of evaporation and condensation allows solar thermal energy to be used much more efficiently (Zaragoza et al., 2006). Watergy prototype in a closed greenhouse reduced water and energy consumption. Beans (*Phaseolus vulgaris*), okra (*Abelmoschus esculentus*), and kenaf (*Abelmoschus cannabinus*), remained healthy inside the greenhouse in all seasons and this closed greenhouse improved production compared to traditional open greenhouses and reduced water consumption by 80 % (Zaragoza and Buchholz, 2008).

Rice is a plant with high water requirements and its cultivation is usually limited to humid areas. Cultivation of this plant in arid and semi-arid regions of the world destroys water resources and has no economic or environmental justification. One of the ways to reduce evapotranspiration in rice is to use a closed culture system so that due to the high relative humidity around the plant, the rate of evapotranspiration is reduced. This may only be possible in the vegetative stage of the plant due to potential problems for the plant. Therefore, this study aimed to determine the level of reduction of evapotranspiration that did not have an adverse effect on the vegetative growth of rice.

2. Materials and Methods

This research was conducted as a pot experiment based on a completely randomized design with three replications on rice plants at Razi University in 2018. For this purpose, fifteen pots were considered, each of which was filled with field soil. To control evapotranspiration, a plastic pot with a lid that was transparent to light was used so that the photosynthesis of the plant was not disturbed. On 4/14/2018, each plastic pot with a height of 5 cm was filled with soil. Then 25 rice seeds were sown per pot. After germination, seedlings were thinned to the desired number. The light, temperature, etc. were the same for all treatments.

Experimental treatments included: Treatment 1: 100 % control of evapotranspiration (The lid of the pot was always closed), Treatment 2: The pot lid was closed and the lid was left open for one hour every day. Treatment 3: The pot lid was closed and the lid was left open for one hour every two days, Treatment 4: The pot lid was closed and the lid was left open for one hour every three days, Treatment 5 (control): No control of evapotranspiration (pot lid was always open).

Irrigation time was determined according to soil appearance. To do this, before the dark color due to moisture in the soil changes and the soil comes out of the flooded state, irrigation was carried out by flooding so that some water (about 1 cm) was collected on the soil surface. On 5/7/2018, 0.4 g of urea fertilizer was dissolved in 10 ml of water and added to the treatments.

On 5/26/2018, the plants were harvested. Plant height, number of leaves per plant, stem diameter, leaf area, root fresh weight, root volume, leaf fresh weight, leaf dry weight, leaf relative water content, water consumption, and water use efficiency were measured.

Plant height was measured with a ruler. Caliper was used to measure stem diameter. To measure the relative water content of the leaves, first, the fresh leaf weight was measured with a digital scale with milligram accuracy immediately after cutting the last developed leaf of the plant. Then, to calculate the turgid weight of the leaf, the leaves were placed in distilled water at room temperature for 24 hours. Immediately after the leaves were removed from the distilled water, their surface moisture was dried with the help of a tissue and their turgid weight was measured. Finally, the leaves were dried in an oven at 75 ° C for 24 hours. The relative water content of the leaves was obtained using the formula of Moradi et al. (2016) as follows:

$$RWC\ (\%) = (FW - DW / TW - DW) \times 100\% \quad (1)$$

where, RWC, FW, DW, and TW are leaf relative water content, leaf fresh weight, leaf dry weight, and leaf turgid weight, respectively.

The relationship presented by Heidari and Kahrizi (2018) was used to measure the leaf area of rice after measuring the length and width of the leaf as follows:

$$\text{Leaf area } (cm^2) = \text{leaf length (cm)} \times \text{leaf width (cm)} \times 0.7 \quad (2)$$

The water used in each irrigation time was measured with a graduated container and the total was recorded as water consumption per pot. To measure water use efficiency (WUE), the following equation was used (Heidari et al., 2022):

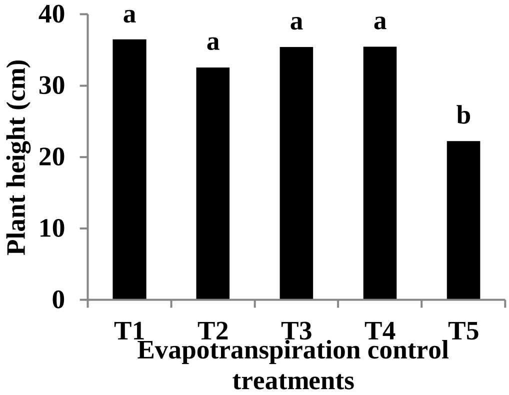
$$\text{WUE (mg/ml)} = \text{Plant biomass (mg)} / \text{Water consumption (ml)} \quad (3)$$

A graduated cylinder was used to measure root volume. In this way, after filling the graduated cylinder with water and measuring the initial volume of water in the graduated cylinder, the fresh roots of the plant were submerged in water, and immediately the number related to the change of water volume was measured. The volume of water transferred was equivalent to the volume of roots (Böhm, 2012).

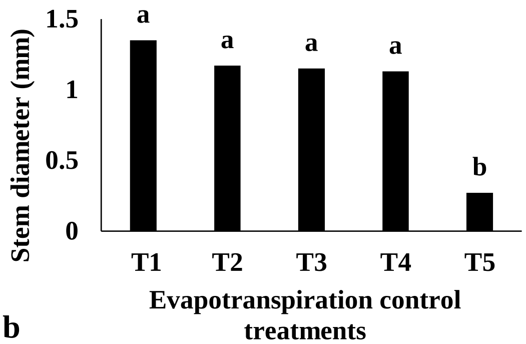
The data obtained from the experiment were analyzed by SAS software. Mean data were compared with the LSD test at a probability level of 0.05. Excel program was used to draw the charts.

3. Results and Discussion

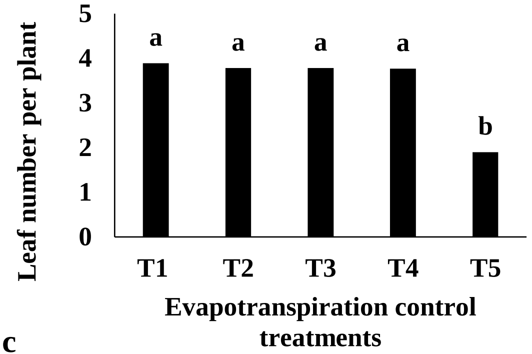
Mean data comparison showed that the treatment of no control of evapotranspiration (control) had the lowest plant height (Fig. 1a), stem diameter (Fig. 1b), and the number of leaves per plant (Fig. 1c) of rice compared to other methods of evapotranspiration control. Polyethylene mulch increased soil moisture, soil temperature, and EC and decreased phosphorus, thereby reducing plant growth (root length, root diameter, relative growth rate of plant height and leaf area, and shoot and root biomass) and fruit yield in tomato (Zhang et al., 2019). Ridge-furrow with plastic mulching compared to traditional irrigation planting reduced the plant height of maize and increased its resistance to stem loading (Li and Li, 2021). Ridge-furrow plastic mulching increased soil moisture, leaf growth, and water use efficiency in maize (Zhang et al., 2021c). It seems that the loss of moisture by evaporation and transpiration has reduced the morphological characteristics of rice such as plant height, stem diameter, and the number of leaves per plant. The plastic cover of the pot prevents the loss of moisture and improves the growth characteristics of the plant.



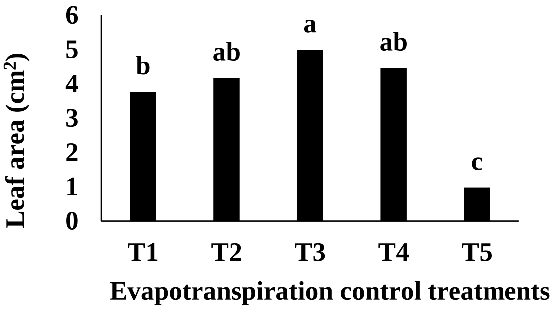
a



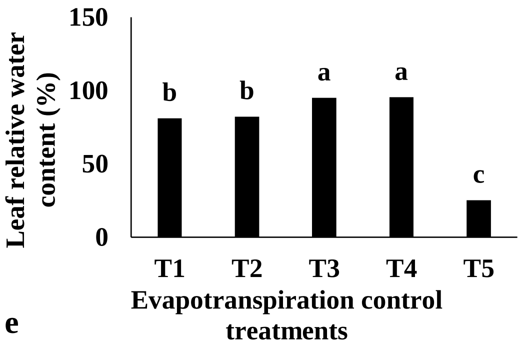
b



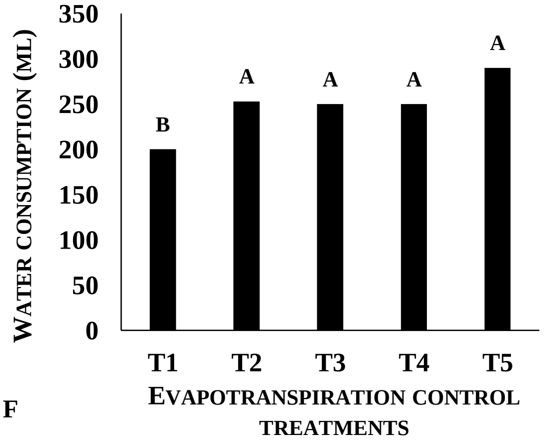
c



d



e



F

Fig. 1. Mean comparisons for the effect of evapotranspiration control treatments on some morphophysiological traits in rice. **a:** Plant height, **b:** Stem diameter, **c:** Leaf number per plant, **d:** Leaf area, **e:** Leaf relative water content, and **f:** Water consumption. T1: 100 % control of evapotranspiration (The lid of the pot was always closed), T2: The pot lid was closed and the lid was left open for one hour every day. T3: The pot lid was closed and the lid was left open for one hour every two days, T4: The pot lid was closed and the lid was left open for one hour every three days, and T5: Control, no control of evapotranspiration (pot lid was always open). Means with the same letter are not significantly different according to the LSD test at the probability level of 5 %.

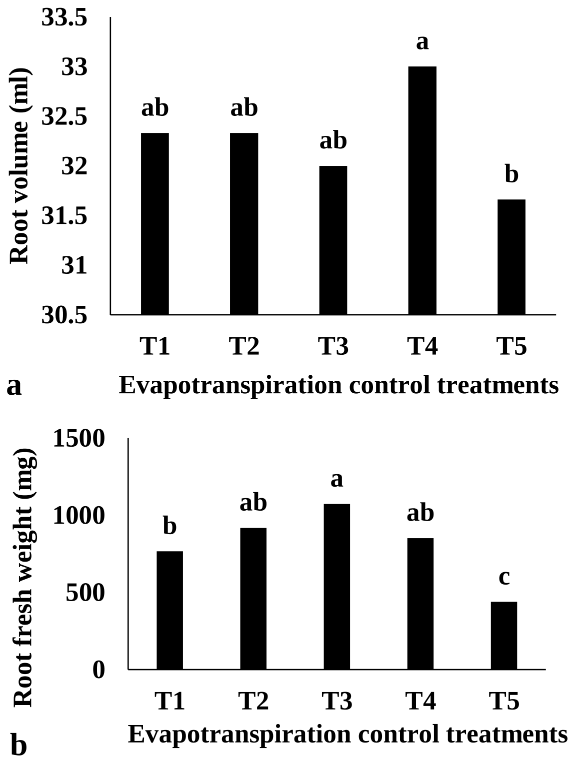
The control treatment (no control of evapotranspiration) had the lowest leaf area (Fig. 1d) and the leaf relative water content (Fig. 1e) compared to the evapotranspiration control treatments. Lafitte (2002) investigated the relationship between the leaf relative water content and the yield of rice cultivars and reported that when drought stress is severe, there may be a relationship between yield and leaf relative water content, which is consistent with the results of this research. Because in the present study, the biomass of the plant also decreased with the decrease in the leaf relative water content. Zhang et al. (2023) reported the reduction of rice leaf area under drought stress conditions, which is consistent with the results of the present study. Rice is a plant with high water requirements and in addition to providing moisture from the soil, it likes high air relative humidity (Abeysiriwardena et al., 2002). Hirai et al. (2000) reported that high air relative humidity increased plant height, leaf length, and leaf width in rice seedlings, but decreased leaf emergence rate, number of roots, root length, and leaf area. With decreasing plant water requirement and not using plastic mulch, the leaf relative water content of peppermint decreased, while the use of plastic mulch increased the leaf relative water content (Shahriari et al., 2013). Decreased leaf area in 100 % evapotranspiration control treatment compared to treatment of keeping pot lid open every two days for one hour might be due to the fact that high air relative humidity in rice-growing medium could partially prevent transpiration and temporarily stop photosynthesis (Heidari and Mohammadi, 2011) or reduced plant growth by increasing disease (Jia et al., 2015). Therefore, the decrease in leaf area and leaf relative water content in rice may be due to air with low relative humidity because in other treatments, due to the closed environment of the pot, probably the air around the plant is almost saturated with moisture. Regarding the relative water content of the leaf, it can be said that the presence of the leaf in the medium saturated with moisture can help increase the leaf water, and the unsaturated environment of moisture can probably reduce the relative water content of the leaf by transpiration.

100 % control of evapotranspiration had the lowest water consumption (Fig. 1f). In closed pots, due to the high relative humidity of the air inside the pot, the tendency of water molecules to convert from liquid to vapor decreases. The mechanism of transfer of water molecules from liquid to vapor is such that water molecules are connected in groups by hydrogen bonding. There are some water molecules alone. The ratio of molecules attached to single molecules depends on the temperature of the environment, and these molecules are rapidly changing positions between the individual and the bonded state. During this displacement, some molecules may be out of gravity and evaporate, moving faster. The escape of a water molecule is called evaporation, and the resulting pressure is called water vapor pressure. Water vapor pressure depends on the temperature. In a closed system, evaporation continues until the air is saturated, then stops. As air saturates with water vapor, the probability of steam molecules colliding with each other due to gravity increases, and this is the same factor in the formation of fog and dew. Therefore, the amount of steam does not exceed a certain amount, which is called the saturation concentration, and if a larger amount of moisture evaporates, it will condense at the same amount elsewhere (Meidani, 1991; Hlastala, 2006).

The control treatment (no control of evapotranspiration) had the lowest root volume (Fig. 2a) and root weight (Fig. 2b) compared to the evapotranspiration control treatments. Ridge-furrow plastic mulching compared to flat planting changed the soil moisture pattern and root growth pattern in maize. Ridge-furrow plastic mulching resulted in increased root growth in the surface and middle parts of the soil, which was due to the increase in soil moisture content and increase in surface moisture relative to deep soil moisture (Zhang et al., 2021a). Results of 36 independent field studies showed that plastic mulch increased root weight density, root length density, and root diameter (Li et al., 2021). It seems that better moisture status in evapotranspiration control treatments has increased the weight and volume of rice roots.

The control treatment (no control of evapotranspiration) had the lowest leaf fresh weight (Fig. 2c) and leaf dry weight (Fig. 2d) compared to the evapotranspiration control treatments. Leaf anatomy in maize under plastic mulch changed compared to without mulch. Various parameters in leaves, including leaf thickness and mesophilic layer, xylem, substomatal chamber, and intercellular canal for plastic mulch were significantly lower than treatment without mulch. However, lower epidermis thickness and phloem area were not significantly different between mulch and non-mulch treatments. Changes in root growth and leaf anatomy led to increased photosynthesis, seed yield, and biomass under plastic mulching (Niu et al., 2020). The improvement in leaf weight in rice evapotranspiration control treatments is probably due to the improvement of moisture conditions for leaf photosynthesis, which has led to continued photosynthesis and biomass production in the leaves.

The control treatment (no control of evapotranspiration) had the lowest water use efficiency (Fig. 2e) compared to the evapotranspiration control treatments. Increasing the water vapor pressure deficit reduced the photosynthesis, dry matter production, and water use efficiency of potato (*Solanum tuberosum* L.) cultivars (Kaminski et al., 2014). No control of evapotranspiration causes the plant to use too much moisture. In these conditions, the loss of moisture by the air is maximized. The control treatment had the highest water consumption and the lowest dry matter production in rice shoots and roots. Mulches act as a barrier to the release of water molecules as water vapor from the plant environment. The change of water state from liquid to vapor occurs faster when there is no obstacle in front of it. Plastic mulch in pots, like the roof of a greenhouse, prevents water molecules from escaping and traps them, increasing the relative humidity around the plant. The higher the relative humidity of the environment, the lower the tendency of water molecules to change state from liquid to water vapor. At high atmospheric relative humidity conditions, atmospheric tension for evaporation is usually lower and water use efficiency increases (Ben-Asher et al., 2013; Fanourakis et al., 2020).



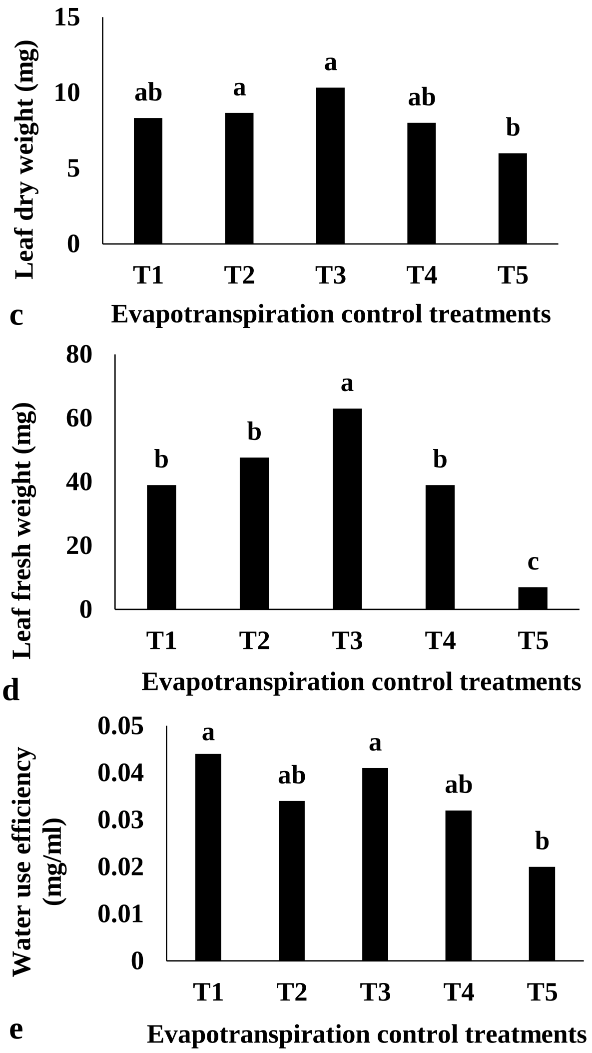


Fig. 2. Mean comparisons for the effect of evapotranspiration control treatments on root, leaf, and water use efficiency in rice. a: Root volume, b: Root fresh weight, c: Leaf fresh weight, d: Leaf dry weight, and e: Water use efficiency. T1: 100 % control of evapotranspiration (The lid of the pot was always closed), T2: The pot lid was closed and the lid was left open for one hour every day. T3: The pot lid was closed and the lid was left open for one hour every two days, T4: The pot lid was closed and the lid was left open for one hour every three days, and T5: Control, no control of evapotranspiration (pot lid was always open). Means with the same letter are not significantly different according to the LSD test at the probability level of 5 %.

4. Conclusions

The treatment without controlling evapotranspiration had the lowest plant height, stem diameter, number of leaves, leaf area, leaf relative moisture content, root fresh weight, and leaf fresh weight. The 100% evapotranspiration control treatment had the lowest water consumption and the highest water use efficiency. Overall, the results of this study showed that it is possible to plant crops such as rice in a closed environment in terms of humidity. Reducing the evapotranspiration of plants such as rice that are adapted to high relative humidity with the help of a closed environment such as plastic in the field or greenhouse can prevent moisture loss in arid and semi-arid regions and prevent the destruction of water sources.

5. Disclosure statement

No potential conflict of interest was reported by the authors.

6. References

Abeysiriwardena, D. S., Kazuhiko, O., & Maruyama, A. (2002). Influence of temperature and relative humidity on grain sterility in rice. *Journal of the National Science Foundation of Sri Lanka, 30*, 33-41. DOI: 10.4038/jnsfsr.v30i1-2.2559.

Adekaldu, E., Amponsah, W., Tuffour, H.O., Adu, M.O., & Agyare, W.A. (2021). Response of chilli pepper to different irrigation schedules and mulching technologies in semi-arid environments. *Journal of Agriculture and Food Research, 6*, 100222. DOI: 10.1016/j.jafr.2021.100222

Ben-Asher, J., Garcia, y., Garcia, A., Flitcroft, I., & Hoogenboom, G. (2013). Effect of atmospheric water vapor on photosynthesis, transpiration and canopy conductance: A case study in corn. *Plant, Soil and Environment, 59* (12), 549-555. DOI: 10.17221/346/2013-PSE

Böhm, W. (2012). *Methods of studying root systems*. Springer Berlin Heidelberg, 188 pages.

Chai, Y., Chai, Q., Li, R., Li, Y., Yang, C., Cheng, H., Chang, L., & Chai, S. (2021). Straw strip mulching in a semiarid rainfed agroecosystem achieves winter wheat yields similar to those of full plastic mulching by optimizing the soil hydrothermal regime. *The Crop Journal*, DOI: 10.1016/j.cj.2021.09.004

Fang, H., Li, Y., Gu, X., Yu, M., Du, Y., Chen, P., & Li, Y. (2021). Evapotranspiration partitioning, water use efficiency, and maize yield under different film mulching and nitrogen application in northwest China. *Field Crops Research, 264*, 108103. DOI: 10.1016/j.fcr.2021.108103

Fanourakis, D., Aliniaeifard, S., Sellin, A., Giday, H., Körner, O., Rezaei Nejad, A., Delis, C., Bouranis, D., Koubouris, G., Kambourakis, E., Nikoloudakis, N., & Tsaniklidis, G. (2020). Stomatal behavior following mid- or long-term exposure to high relative air humidity: A review. *Plant Physiology and Biochemistry, 153*, 92-105. DOI: 10.1016/j.plaphy.2020.05.024

Haque, M.A., Jahiruddin, M., & Clarke, D. (2018). Effect of plastic mulch on crop yield and land degradation in south coastal saline soils of Bangladesh. *International Soil and Water Conservation Research, 6*, 317-324. DOI: 10.1016/j.iswcr.2018.07.001

Heidari, H., & Kahrizi, D. (2018). Effect of water stress and contaminated water on seed germination traits and early growth in maize (*Zea mays*). *Environmental Engineering and Management Journal, 17*(1), 35-42. DOI: 10.30638/eemj.2018.005

Heidari, H., & Mohammadi, H. (2011). *Crop physiology*. Tehran: Dibagaran Publication.

Heidari, H., Zarei, Z., & Mohammadi K. (2022). Improving water use efficiency and biomass in maize, foxtail millet, and bitter vetch by wick irrigation. *Water SA*, *48* (3), 264-270. DOI: 10.17159/wsa/2022.v48.i3.3913

Hirai, G., Okumura, T., Takeuchi, Sh., Tanaka, O., & Chujo, H. (2000). Studies on the effect of the relative humidity of the atmosphere on the growth and physiology of rice plants. *Plant Production Science, 3* (2), 129-133. DOI: 10.1626/pps.3.129

Hlastala, M.P. (2006). *Ventilation | Overview*. In: Laurent, G.J., & Shapiro, S.D. (Eds.), Encyclopedia of respiratory medicine (pp. 428-434). Oxford: Academic Press. DOI: 10.1016/B0-12-370879-6/00424-5

Jia, Q., Lv, B., Guo, M. Luo, Ch., Zheng, L., Hsiang, T., & Huang, J. (2015). Effect of rice growth stage, temperature, relative humidity and wetness duration on infection of rice panicles by *Villosiclava virens*. *European Journal of Plant Pathology, 141*, 15-25. DOI: 10.1007/s10658-014-0516-4

Kaminski, K.P., Kørup, K., Nielsen, K.L., Liu, F., Topbjerg, H.B., Kirk, H.G., & Andersen, M.N. (2014). Gas-exchange, water use efficiency and yield responses of elite potato (*Solanum tuberosum* L.) cultivars to changes in atmospheric carbon dioxide concentration, temperature and relative humidity. *Agricultural and Forest Meteorology, 187*, 36-45. DOI: 10.1016/j.agrformet.2013.12.001

Lafitte, R. (2002). Relationship between leaf relative water content during reproductive stage water deficit and grain formation in rice. *Field Crops Research*, *76* (2–3), 165-174. DOI: 10.1016/S0378-4290(02)00037-0.

Li, C., & Li, C. (2021). Ridge-furrow with plastic film mulching system decreases the lodging risk for summer maize plants under different nitrogen fertilization rates and varieties in dry semi-humid areas. *Field Crops Research, 263*, 108056. DOI: 10.1016/j.fcr.2021.108056

Li, Y., Yang, J., Shi, Z., Pan, W., Liao, Y., Li, T., & Qin, X. (2021). Response of root traits to plastic film mulch and its effects on yield. *Soil and Tillage Research, 209*, 104930. DOI: 10.1016/j.still.2020.104930

Li, Y.-S., Wu, L.-H., Zhao, L.-M., Lu, X.-H., Fan, Q.-L., & Zhang, F.-S. (2007). Influence of continuous plastic film mulching on yield, water use efficiency and soil properties of rice fields under non-flooding condition. *Soil and Tillage Research, 93*, 370-378. DOI: 10.1016/j.still.2006.05.010

López-Urrea, R., Sánchez, J.M., Montoro, A., Mañas, F., & Intrigliolo, D.S. (2020). Effect of using pruning waste as an organic mulching on a drip-irrigated vineyard evapotranspiration under a semi-arid climate. *Agricultural and Forest Meteorology, 291*, 108064. DOI: 10.1016/j.agrformet.2020.108064

Meidani, J. (1991). *Principles of processing and storage of agricultural products*. Ahvaz: Shahid Chamran University of Ahvaz Publications.

Mendonça, S.R., Ávila, M.C.R., Vital, R.G., Evangelista, Z.R., Pontes, N.d.C., & Nascimento, A.d.R. (2021). The effect of different mulching on tomato development and yield. *Scientia Horticulturae, 275*, 109657. DOI: 10.1016/j.scienta.2020.109657

Moradi, S., Heidari, H., Saeidi, M., Nosratti, I. (2016). Effect of sewage-contaminated water on seed production, heavy metals accumulation and seedling emergence in oat. *Global nest Journal, 18* (2), 329-338. DOI: 10.30955/gnj.001838

Niu, L., Yan, Y., Hou, P., Bai, W., Zhao, R., Wang, Y., Li, S., Du, T., Zhao, M., Song, J., & Zhou, W. (2020). Influence of plastic film mulching and planting density on yield, leaf anatomy, and root characteristics of maize on the Loess Plateau. *The Crop Journal, 8*, 548-564. DOI: 10.1016/j.cj.2019.12.002

Shahriari, S., Azizi, M., Aroiee, H., & Ansari, H. (2013). Effect of different irrigation levels and mulch application on growth parameters and essential oil content of peppermint (*Mentha piperita* L.). Iranian *Journal of Medicinal and Aromatic Plants, 29* (3), 568-582.

Sibo, C., Liang, T., Jian, S., Quan, X., Zhengjin, X., & Wenfu, C. (2021). Contribution and Prospect of Erect Panicle Type to japonica Super Rice. *Rice Science, 28*, 431-441. DOI: 10.1016/j.rsci.2021.07.004

Vos, J.G.M., Uhan, T.S., & Sutarya, R. (1995). Integrated crop management of hot pepper (Capsicum spp.) under tropical lowland conditions: Effects of rice straw and plastic mulches on crop health. *Crop Protection, 14*, 445-452. DOI: 10.1016/0261-2194(94)00012-W

Wang, L., Iddio, E., & Ewers, B. (2021). Introductory overview: Evapotranspiration (ET) models for controlled environment agriculture (CEA). *Computers and Electronics in Agriculture, 190*, 106447. DOI: 10.1016/j.compag.2021.106447

Wang, Y., Zou, Y., Cai, H., Zeng, Y., He, J., Yu, L., Zhang, C., Saddique, Q., Peng, X., Siddique, K.H.M., Yu, Q., & Su, Z. (2022). Seasonal variation and controlling factors of evapotranspiration over dry semi-humid cropland in Guanzhong Plain, China. *Agricultural Water Management, 259*, 107242. DOI: 10.1016/j.agwat.2021.107242

Zaragoza, G., & Buchholz, M. (2008). Closed greenhouses for semi-arid climates: Critical discussion following the results of the Watergy prototype. *Acta horticulturae*, DOI: 10.17660/ActaHortic.2008.797.2

Zaragoza, G., Buendía, D., & Pérez, J. (November, 2006). Project watergy: a closed greenhouse for minimized water consumption and optimized solar energy use. *CIES 2006 – XIII Congresso Ibérico e VIII Congresso Ibero-Americano de Energia Solar* 9-10 Novembro 2006, Lisboa, 9 pages.

Zhang, G., Meng, W., Pan, W., Han, J., & Liao, Y. (2021a). Effect of soil water content changes caused by ridge-furrow plastic film mulching on the root distribution and water use pattern of spring maize in the Loess Plateau. *Agricultural Water Management*, 107338. DOI: 10.1016/j.agwat.2021.107338

Zhang, L., Qin, R., Wei, H., Zhang, K., Yu, C., Li, F.-M., & Zhang, F. (2021b). Optimum plastic mulching application to reduce greenhouse gas emissions without compromising on crop yield and farmers' income. *Science of The Total Environment*, 151998. DOI: 10.1016/j.scitotenv.2021.151998

Zhang, X., You, S., Tian, Y., & Li, J. (2019). Comparison of plastic film, biodegradable paper and bio-based film mulching for summer tomato production: Soil properties, plant growth, fruit yield and fruit quality. *Scientia Horticulturae, 249*, 38-48. DOI: 10.1016/j.scienta.2019.01.037

Zhang, X.-F., Luo, C.-L., Mo, F., Ren, H.-X., Mburu, D., Kavagi, L., Dai, R.-Z., Wesly, K., Ren, A.-T., Nyende, A.B., & Xiong, Y.-C. (2021c). Density-dependent maize (*Zea mays* L.) yield increase in trade-off in reproductive allocation and water use under ridge-furrow plastic-mulching. *Field Crops Research, 264*, 108102. DOI: 10.1016/j.fcr.2021.108102

Zhang, Y., Zhao, X., Liu, F., Zhu, L., & Yu, H. (2023). Effect of different water stress on growth index and yield of semi-late rice. *Environmental Sciences Proceedings*, *25* (1), 84. DOI: 10.3390/ECWS-7-14318.