The combined irrigation of sweet pepper

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Abstract. The advantages of drip irrigation of many agricultural crops are well known, but it does not allow to regulate the phytoclimate in the "environment-plant" system, which is especially important for the conditions of the hot and dry climate of the Republic of Dagestan. Currently, the efficiency of fine sprinkling on the background of drip irrigation was insufficiently studied, as questions remain the combined effect of irrigation on crop productivity in real climatic conditions on the effectiveness of combination with other agronomic techniques, etc. Experimental studies were conducted on the experimental field of the Department of Agriculture, Soil Science and Land Reclamation in the educational and experimental farm of the Dagestan State Agrarian University. The main purpose of the research was to determine the parameters of the combined irrigation technology, its effect on the microclimate of the irrigated field and the phytoclimate of plants, as well as the productivity of sweet pepper. As the result of experimental studies, it was found that the use of a combined irrigation system (drip irrigation + fine sprinkling) when cultivating sweet pepper allows to obtain an additional 9.4 t/ha of marketable products by optimizing the growing conditions.

1. Introduction

The Republic of Dagestan ranks first in terms of vegetable production in the Russian Federation, with about 98% of vegetables grown in private gardens and farms, but the level of technologies used does not meet the modern requirements. Hence, it followed by the low yield (33.6 t/ha) and low marketability of products, which do not exceed a third of the volume produced [1].

The frequency of arid and acutely arid periods in the republic is very high, and even in conditions of irrigated agriculture, agricultural crops are exposed to dry winds accompanied by atmospheric droughts many times during the growing season. In such conditions, humidifying irrigation is a reliable means of preserving and increasing the yield. One of the ways to solve the problem of combating air drought is to develop the irrigation systems using mist irrigation (MI) to regulate the phytoclimate in the hot hours of the day. These studies were carried out by the author even in 1975-1978 on the fruit-bearing vineyards of Dagestan, where the use of MI against the furrow irrigation allowed to increase the yield of grapes by 3.2 t/ha with significant savings in irrigation water [2].

At the present stage of the irrigated agriculture development, an integrated approach to evaluating the effectiveness of irrigation systems is more relevant than ever. Such factors as environmental safety and resource conservation of not only water, but also other resources in the production of agricultural products come to the fore [3, 4, 5, 6]. The use of modern agricultural technologies, such as drip irrigation, in particular, and in combination with mist irrigation will increase the yield on existing areas and the
marketability of vegetable products produced in the republic, as well as solve the problem of water supply for crops with a shortage of irrigation water, especially in the summer [7, 8, 9].

In the hot and dry climate of Dagestan, especially in July and August, characterized by high temperatures, low relative humidity and high solar insolation, plants and fruits are often overheated during their maturation, which reduces the sweet pepper crop quantity and quality. The situation is further complicated by the northwestern winds blowing from the dry steppe zone and reducing the air humidity.

In July, when the pepper active fruiting period begins, the above weather phenomena do not contribute to obtaining maximum plant productivity. The improvement of these phenomena and the creation of an optimal phytoclimate for sweet pepper plants can be achieved by using drip irrigation together with the mist irrigation, which regulates the micro- and phytoclimate of the irrigated field.

2. Materials and methods

Currently, the effectiveness of mist irrigation against the drip irrigation has not been sufficiently studied, since the problem of the combined irrigation influence on the crops productivity in real climatic conditions, on the effectiveness of combination with other agricultural techniques, etc. remains unresolved. The experimental studies were carried out on the experimental field of the Department of agriculture, soil science and land reclamation in the scientific and experimental farm of the Dagestan State Agrarian University. The main purpose of the research was to determine the parameters of combined irrigation technology, its impact on the microclimate of the irrigated field and the phytoclimate of plants, as well as the sweet pepper productivity.

The combined drip irrigation system (DI) with mist irrigation (MI) is meant to maintain a micro- and phytoclimate in the plant environment by reducing the air temperature and increasing the relative humidity of the air, due to periodic spraying of low-intensity rain. The system is able to work independently in the mode of drip irrigation and in the mode of mist irrigation. The technical development of the combined irrigation system allows to produce DI and MI simultaneously, depending on the task (Figure 1).

![Figure 1](image)

**Figure 1.** The combined drip irrigation system (DI) with mist irrigation (MI): 1 - water intake, 2 - pumping station, 3 - filter, 4 - hydraulic feeder, 5 - pressure regulator, 6 - main pipeline, 7 - shut-off valves, 8 - 50 mm section pipeline for drip irrigation, 9 - 50 mm section pipeline for DI + MI, 10 - drip irrigation pipeline, 11 - dropper, 12 - DI + MI irrigation pipeline, 13 - MI installation with a spray nozzle and a bypass valve, 14 - start-connector, 15 - water pressure monitoring gauge, 16 - hydraulic feeder for foliar top dressing and pesticides.
In this system, an additional section pipeline was added to the complete set for more rational and economical use of irrigation water, reducing the MI nozzles and removing energy loads during the operation of the combined system and the hydraulic feeder 16. The additional section pipeline and the main section pipeline are hydraulically connected to the main pipeline by means of saddles, as well as to irrigation pipelines, in the cavities of which droppers are installed in 400 mm increments. An additional pipeline allows to reduce the number of mist irrigation units by 2 times and temporarily remove from service half of the drip lines of the irrigation system during the operation cycle of the MI.

One end of the irrigation combined pipeline with a diameter of 20 mm is connected to the additional section pipeline 9 by a split connection, adapter threaded sleeve and collet clamp. In the wall of the section additional distribution pipeline 9, a water outlet with a diameter of 15 mm is made, in which a start connector is mounted for connecting the section pipeline 9 with combined irrigation pipelines 12. The combined irrigation system works as follows: when the water pressure in irrigation pipelines is up to 0.01...0.13 MPa, drip irrigation is performed. When the water pressure is raised from 0.15 to 0.2 MPa, the bypass valves 13 are activated on the spray nozzles, and mist irrigation is performed, and the drip lines are disconnected from the water supply and distribution process.

The development of this irrigation system, placement scheme and installation of mist irrigation units ensure a stable operation of the combined system under various schemes of sowing the cultivated crops. The number of drip irrigation pipelines per 1 ha may increase depending on the seeding schemes (from two to four and eight line schemes) and the cultivated crop.

To achieve this goal, the field experience was performed according to the following scheme: version 1 is the maintenance of the pre-irrigation threshold with drip irrigation during the entire vegetation period not lower than 70% of field moisture capacity, control; version 2 is the same, but with the use of mist irrigation during the "technical maturity-last harvest" period on the days with the air temperature of more than 25 °C. Refreshing irrigation was carried out by periodic spraying of low-intensity rain in the form of fine droplets no larger than 600 microns using spray nozzles for MI from 9-10 to 16-17 hours with a daily irrigation rate in the range of 5.6...12.0 m³/ha.

The physical essence of MI is periodic wetting of plants with finely dispersed water, and the degree of drops dispersion should correspond to such sizes that they do not roll off the leaves to the soil, but remain on them until complete evaporation. MI technology consists in periodical covering the plants leaf surface with water drops no more than 600 microns in diameter, which remain on them until complete evaporation.

To maintain the pre-irrigation threshold of at least 70% of the field moisture capacity, the irrigation rate of 216 m³/ha was required, and 2.3 hours were allocated for the irrigation period itself during the day. In July-August, depending on the soil moisture, the inter-irrigation period for drip irrigation ranged from 4 to 6 days.

3. Results and discussion

Research showed that the technology of combined irrigation depends on such factors as temperature and humidity, the intensity of solar insolation, wind speed and time of day that affect the interval between humidifications, the duration of work during the day, the length of the irrigation period.

Refreshing irrigation based on MI at the air temperature of more than 25...30 °C was performed at intervals of 60 minutes or 7...9 times during the day, and at the temperature of more than 30...35 °C – at intervals of 30 minutes from 11 to 15 times, depending on the duration of the temperature stress.

The choice of this interval for moistening the pepper plants leaf surface depended on the water droplets evaporation duration from the leaf surface after MI and restoration of the leaf temperature before the start of refreshing watering. Determination of leaf temperature every 10 minutes after the MI showed that at the air temperature of more than 25 °C, water droplets evaporated after 37...43 minutes, and the recovery of leaf surface temperature due to relaxation from humidification continues for another 19...27 minutes. This caused the interval between humidifications of 1 hour (Figure 2). Similar observations of the temperature of the leaf apparatus at the air temperature of more than 30 °C and 35 °C during MI showed that the effect of refreshing watering is reduced to 30...40 minutes (Figure 3, 4).
**Figure 2.** Change in leaf temperature at the air temperature of 25 °C after MI.

**Figure 3.** Change in leaf temperature at the air temperature of 30 °C after MI.

**Figure 4.** Change in leaf temperature at the air temperature of 35 °C after MI.
On average, over the years of research in the interphase period "technical maturity - the last harvest" on the control version 13...15 irrigations were carried out with drip irrigation, and in the experimental version, 1...2 irrigations less, but with refreshing irrigations, on average 304 times and with the irrigation rate of 0.8 m$^3$/ha. The observations over the moisture content in the soil showed that in the experimental version, the soil moisture decreased more slowly than in the control one, and this led to the decrease in the number of irrigations by 1...2 with drip irrigation. In our opinion, this is due to the fact that MI reduces the loss of moisture by plants for transpiration, which contributes to greater moisture retention in the active layer and, accordingly, shifts the timing of regular watering and, as the result, reduces their number.

The studies and observations of the experimental field and plants micro- and phytoclimate confirm this. The air temperature and humidity were measured at the level of 0.5 m among plants by using an aspiration psychrometer. The observations showed that MI reduces the air temperature during the maximum stress of climatic factors (15 hours) by 3.6 °C compared to the drip irrigation site and by 5.5 °C compared to the air temperature in the Stevenson screen. Further, the temperature gradient between the versions with DI and DI + MI decreases to 1.2...2.8 °C, and by the end of humidifying irrigation (19 hours), the difference in air temperature decreases to 1.2...1.4 °C.

The decrease in the air temperature in the plant environment, and the evaporation of drop-liquid moisture from the sweet pepper plants leaf surface contributed to a significant increase in the relative humidity of the air in the plant environment. Thus, in the morning and evening hours, the air humidity between the versions was 8.0...10.5%, and by increasing the temperature stress, the use of MI contributed to the increase in air humidity by 18.0...21.2% compared to the DI version. The micro- and phytoclimate optimization contributed to the decrease in leaf temperature by 5.8 ... 7.1 °C.

Reducing the air temperature and increasing its humidity, along with optimizing the temperature of the sweet pepper plants leaf apparatus, created, in all likelihood, more favorable conditions for reducing the midday depression of photosynthesis and longer reproductive work of the leaf apparatus, which is manifested both in the number of fruits set and in the increase in their average weight (Table 1).

| Table 1. Indicators of sweet pepper productivity under combined irrigation. |
|-----------------------------|----------------|----------------|----------------|----------------|
| Indicators                  | 2011 | 2012 | 2013 | 2011-2013 |
| Duration of MI work (days)  | - 37 | - 30 | - 16 | - 28       |
| Irrigation rate, m$^3$/ha   | 4320 | 4218 | 5054 | 4752       |
| Water consumption coefficient, m$^3$/t | 122.8 | 91.3 | 93.7 | 88.9       |
| Average fruit weight, g     | 40.1 | 42.9 | 51.2 | 57.1       |
| Number of fruits, pcs/bush  | 23.3 | 28.1 | 27.9 | 26.1       |
| Yield, t/ha                 | 43.6 | 58.5 | 67.9 | 71.3       |
| Marketability, %            | 84.3 | 90.6 | 83.1 | 84.7       |

The data analysis obtained shows that the greatest effect of MI was in 2012 and 2013, when the duration of the irrigation period was 30...37 days. This contributed to a certain reduction in the irrigation rate for drip irrigation and a more rational use of irrigation water. The water consumption coefficient in the version with combined irrigation decreased by 16.9...25.7%.

The increase in yield by 16.6% under combined irrigation was 74% due to the increase in the number of fruits per 1 bush and 26% due to the increase in the average weight of the fruit itself. The output of commercial yield increased by 5.7%, which, along with the increase in yields, affected the value of net income.
4. Conclusion

Thus, the application of the combined irrigation system (drip irrigation + mist irrigation) for sweet peppers has a positive effect on the micro- and phytoclimate of plantings, contributes to more economical use of irrigation water and increases crop yield by an average of 16.6%.

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