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# Human Thermoelectric Reassure and Heat Stress in an Arid Greenhouse: The Impact of Evaporative Cooling Use of Fertilizer and Municipal Solid Waste Compost for Developing Peppers in Greenhouses

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## Abstract

Under desert climatic conditions in Riyadh, Saudi Arabia, thermal sensation and heat stress were assessed in a plastic greenhouse with and without evaporative cooling. For the evaluation, appropriate thermal comfort and heat stress scales were chosen. In the greenhouse, measurements of the necessary parameters, including the dry and wet bulb temperatures, globe temperature, natural wet bulb temperature, and solar radiation flux, were made during hot, sunny days. The findings indicated that workers in an uncooled greenhouse would experience high heat stress and would feel very uncomfortable for the majority of the day. At night, however, they would not be at danger for heat stress and would feel at ease. When it comes to comfort and reducing heat stress, efficient evaporative cooling is required during the day but not at night. Workers in the cooled greenhouse are free to engage in any activity, with the exception of noon, when they should adhere to a proposed working schedule in which the various tasks were divided up among the daylight hours depending on the heat stress value. The ideal relative humidity and air temperature ranges in greenhouses are 48-55 percent and 24-28°C, respectively, to prevent heat stress and to maintain comfortable conditions.

In greenhouse pepper (Capsicum annuum L.) cultivation, five different substrates with soil (S) and/or MSWC combinations (0-5-10-20-40 percent) utilised with or without fertigation were used, together with municipal solid waste compost (MSWC) and/or fertigation. The growth of the plants rose by 10–20% MSWC, and fertigation primarily improved plant height. In S: MSWC 80: 20, the amount of fruits grew without fertiliser. As MSWC content increased, plant biomass increased as well. Regarding leaf fluoresces and plant yield, there were no variations. The addition of MSWC boosted the substrate's nutritional value (N, K, P, and organic matter), which raised the EC. Fruit fresh weight dropped (up to 31%) as plants were grown in soil with more MSWC. Fruit size varied depending on the amount of MSWC added to the soil, and this had more of an impact on fruit diameter than fruit length. It's interesting to note that the size of marketable fruits shrank as the substrate's MSWC concentration rose, but the addition of fertiliser swung the trend back in the other direction and kept the fruit marketable. Fruit acidity and total phenols were decreased as a result of MSWC, but fruit lightness was increased. There were no variations in the peppers' EC (total coliform and E. coli) and bacteria (fruit dry matter content, fruit firmness, green colour, total soluble sugars, or EC of peppers). Low MSWC level increased plant growth and preserved fruit fresh weight for greenhouse peppers without impacting plant output, although fertigation had a positive effect.

**Keywords:** Greenhouse; Fertiliser; Fertigation

## Introduction

A state of mind that conveys happiness with the surroundings is known as human thermal comfort. Evaporative cooling is frequently used in arid areas to lower the interior temperature of greenhouses during the summer. The environment in greenhouses is typically created to meet the needs of growing crops, which is frequently not ideal for those who are working there. The fundamental reason for this is that the greenhouses that use evaporative cooling have substantially greater relative humidity levels than the outside air. In the greenhouse, high air humidity can cause uncomfortable sensations and heat stress. Evaporative cooling and air stream, on the other hand, can enhance the comfort levels in greenhouses during the hot summer [1]. Employee productivity in greenhouses is decreased by discomfort and heat stress, which can further worsen existing health issues, particularly for older employees. As a result, in order to safeguard their health from heat exhaustion and/or sunstroke, greenhouse personnel should exercise caution when entering the building in the summer heat. It is possible to categorise the factors influencing a person's level of heat stress and thermal comfort. Environmental factors that affect human thermal comfort and heat stress levels include air current speed, mean radiant temperature of the surrounding area, and dry bulb air temperature and relative humidity (Td and RH). Physiological factors include body metabolic heat generation rate (M in met, 1 met = 58.15 W m2), which varies depending on a person's activity level, gender, age, and nationality. Thermal scales were developed based on the energy balance of the human body under comfortable conditions, where the rate of energy generated by a human body (M) should equal the rate of energy required for the external mechanical work (W) plus the rate of energy released from the body through respiration, evaporation, convection, and radiation [2]. These scales are used to determine how humans feel the environment on a mean basis and how much heat stress they are under. As a result, for a person to feel comfortable, heat should be lost at

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a rate of (M-W). Radiation, convection, evaporation from perspiration, skin diffusion, respiratory evaporative heat, and respiratory convective heat loss are the methods used to transfer heat from the body's surface to its surroundings.

Numerous researches have gone into great detail regarding human thermal comfort and heat stress in both indoor and outdoor settings. The majority of these researches examined the environmental factors that affect human habitation in order to assess potential heat stress and thermal comfort in people [3].

Wet bulb globe temperature (WBGT) measurements, however, were made in greenhouses in relatively mild weather. Both people viewed the WBGT as a measure of people's thermal comfort. However, rather than the WBGT, which is a scale of heat stress, the comfort level of workers is typically assessed using the comfort scales. These researches came to the conclusion that the personnel should be cautious and enter the greenhouses around midday to reduce the danger of heat stress [4]. In actuality, worker thermal comfort as well as heat stress levels should be considered while evaluating the greenhouse environment.

In the European Union, each resident produces more than 500 kg of municipal solid waste (MSW) annually. Over the past 30 years, there has been a significant increase in residue generation worldwide, resulting in not only a loss of resources and energy but also detrimental effects on the ecosystem. The application of young composts to soil has been demonstrated in numerous studies to seriously impair plant growth. Large amounts of MSW could be composted to provide material that can be utilised as crop substrate, fertiliser, and an organic soil additive. There are, however, some restrictions on the usage of particular composts, and the physical and chemical qualities of these composts vary significantly. Municipal solid waste compost (MSWC), when implemented as an organic soil supplement in field tests, showed flashes of brilliance for application in agricultural production, enhancing soil physicochemical qualities, increasing water retention, and supplying a sizable amount of critical nutrients [5]. Compost's chemical, physical, and biological characteristics have been examined in several researches on its usage in the development of nursery plants. Compost and perlite combinations (20 to 50 percent MSWC) have been employed in nurseries as substrates without the requirement for additional mineral fertiliser. Maynard noted indicators of damping off infections and squash withering, but reported a 58 percent increased production in tomato crops modified with 11.2 t ha1 MSW compost. After using MSW compost, tomatoes grew and produced more, although the cost was higher than that of commercial fertiliser. The use of MSWC as a soil addition in horticultural crops and its effects on the quality of the fruit, however, are both topics that are not well-covered by the current data [6].

Fruit quality is a broad concept that involves not only taste, colour, nutritional value, and firmness, but also shelf life, processing characteristics, and infection resistance. Only products that meet consumer expectations can survive at the point where the market and supply meet. Fruit firmness is a significant quality characteristic that directly correlates to improved storability potential and increased resistance to mechanical damage and decay. Vegetable eating has also been linked to improved human health and a lower chance of developing some cancers, which has boosted interest in them [7].

The goal of the current study was to assess the effects of mineral fertigation in conjunction with various MSWC soil content mixtures on plant development and fruit quality-related metrics in greenhouse pepper production.

## Material and Methods

### Heat Stress and Thermal Comfort Scales

Using a correlation suggested by the ISO-7234 standard for outside settings, the WBGT (C) may be determined in the greenhouse and is given by as

$$\text{WBGT} = 0.7\ (T\text{nw}) + 0.2\ (Tg) + 0.1\ (Td)$$

Where Tnw (°C) represents the natural wet bulb temperature and TG (°C) represents the globe temperature. The natural wet bulb temperature is often recorded with a thermometer that is covered with a moist, white muslin wick and left out in the open without any ventilation or shade. The surrounding environment is passively exposed to both Tnw and Tg. Different sorts of greenhouse activities are categorised in accordance with the maximum allowable value of the WBGT in order to give greenhouse workers a suitable timetable.

### Experimental Measurements

In a greenhouse with a 48 m2 floor surface, a plastic film covering, and an evaporative cooling system that includes a wet pad and fans, two tests were carried out. The measurement equipment was set up at a height of 2 metres above the greenhouse floor, which was aligned in a north-south orientation. Three suction fans provided mechanical ventilation for the greenhouse [8]. Two 24-hour periods of hot, sunny days were used for the measurements in order to track down the necessary greenhouse parameters. Based on the vertical cross-sectional area and air flow rate in the greenhouse, it was calculated that the average air speed there was around 0.3 m s1. RH.

### Plant Material and Municipal Solid Waste Compost Source

From September to January, pepper plants were grown in the open air with natural lighting. Inter-Municipal Enterprise for the Management of Solid Wastes (IMEMSW), based in Chania, is the fulcrum of Municipal Solid Waste Compost (MSWC). The compost was created using the organic component of urban garbage that had been carefully gathered. The composting process took five to six months. The majority of the compost, 60%, was made up of 4 mm or smaller particles.

### Measurements

We noticed the substrates' physicochemical characteristics. As a result, the K and Na contents, P (spectrophotometrically), total N (Kjeldahl), organic matter and organic carbon contents, pH, and EC were determined.

It was investigated how the substrate media affected pepper plant growth, development, and yield from the second week following transplantation. Plant height, main stem diameter, leaf production, flower and fruit production, and leaf fluorescence were all measured every other week. Plant biomass (fresh weight and the percentage of dry matter) and plant yield were calculated once the experiment was complete.

We assessed fruit fresh weight, dry matter content (in percent), and fruit length and diameter. A 1-4 scale was used to assess the marketability of fruits: 1 for extra quality, 2 for good quality, 3 for middling quality (small size, decolorization), and 4 for unmarketable quality (i.e. malformation, wounds, and infection). Two measurements of fruit colour were made using a Minolta Chroma Meter CR300 around the fruit's equator. In L a b units, data are expressed. Using a penetrometer (FT 011), fruit firmness was assessed at one location on the fruit's shoulder for each treatment (TR Scientific Instruments,

Forli, Italy). Each tomato's radial pericarp (or surface) breaking force (measured in Newtons; N) was noted at room temperature (22–24 °C) [9].

Using a digital refractometer 300017 from Sper Scientific Ltd in Arizona, USA, at 20°C, the total soluble solids (TSSs) content in each treatment's fruit juice was measured. The results were expressed as the mean (percent) of °Brix. The pH of fruit juice was measured with a conventional pH metre using subsamples of homogenised fruit tissue (Orion 920A, Scientific Support, Hayward, CA, USA). Fruit samples (5 g) were diluted in 100 mL of distilled water, titrated with 0.1 N NaOH, and monitored with a pH metre up to 8.2 as the end point for the potentiometric titration method to estimate titratable acidity (TA). Citric acid % was used to express the reported data. Using mixed fruit tissue (5 g) extracts, the total phenolic content was assessed.

## Results

High air temperature (Td), low relative humidity (RH), and intense solar radiation flux (Si) in the arid environment force greenhouses to use evaporative cooling, which is necessary to develop crops and safeguard workers from heat stress dangers. The daily maximum hourly value of Td was reduced by about 7 to 8 degrees Celsius and the daily minimum hourly value of RH was increased by around 20 to 25 percent at around midday as a result of evaporative cooling of the air inside the greenhouse. Because the cushion was outdated and partially blocked with salt on the pad surfaces, the cooling system's efficacy in the current investigation was low (the cooling water used was brackish). Consequently, the decrease in Td and the increase in RH were very modest in comparison to the ideal conditions for crop growth (20-30 C Td and 70-80 percent RH). The influence of water vapour, which weakens and/or absorbs the solar radiation delivered into the greenhouse, may result in a minor reduction in Si. In terms of elements, the pure MSWC had the following values: pH: 7.52, EC: 16.54 mS/cm, organic C: 26.62 percent, total N: 0.57 percent, P: 164 ppm, K: 727 ppm, and Na: 403 ppm. The organic matter content of the soil increased as a result of the addition of MSWC, an organic medium, as well as the pH and EC of the medium, and the values are consistent with other studies. The amount of MSWC added to the soil increased its N, P, K, and Na contents, changing the medium's nutritional value. A useful raw material for the horticulture sector, municipal solid trash can be utilised as a bulking material to absorb excess water because it is between 60 and 90 percent biodegradable.

## Discussion

The evolution of the global thermal climate index through time this index was calculated within a greenhouse over a 24-hour period both with and without air conditioning. The hourly estimated values of Td, RH, and the temperature differential (Tmrt-Td) were the input parameters to the UTCI calculator, which was employed. The time period at which a specific degree of heat stress occurred (based on the UTCI values in) can be used to characterise the amounts of heat stress that occurred in greenhouses throughout the day when there was arid weather. The SET thermal comfort scale, on the other hand, offers more precise data on thermal sensation (TSENS) and discomfort conditions (DISC) during the day and night. It is possible to assess the comfort levels in the cooled greenhouse by using the predictive mean vote index (PMV), which has a limited scale (3 to +3). Utilizing the Ray Man software model as well as PET and SET scales, the PMV value was computed. As a result, the expected percentage of dissatisfaction, or PPD percent, can be determined using the formula PPD = 100 95 Exp (0.03353 PMV4 0.2179 PMV2). Estimated PPD values were shown against Td for the greenhouse that had been refrigerated. According to the data in this graph, the PPD had a minimum value of around 5% when Td was between 24 and 28 degrees Celsius and RH was between 48 and 55 percent.

This indicates that under these circumstances, around 95% of greenhouse employees would be content with their surroundings. These results are consistent with the typical comfort settings, which call for a PPD of 5% at Td = 25°C and a RH of 50%. Cooled feeling and cold stress are produced when Td is less than 24 C and RH is less than 48 percent, whereas heated feeling and thermal stress are produced when Td is greater than 28 C and RH is greater than 55 percent. However, these RH and Td values are typically not ideal for plant growth requirements; therefore this presents additional difficulty that must be taken into account.

The quantity of fruits produced exhibited a similar trend to that of flowers (data not presented). When compared to the control group, plants cultivated in S: MSWC 90: 10 and S: MSWC 80: 20 yielded twice as many fruits at the beginning (the first 45 days) of the experiment. However, in the end, the S: MSWC 80: 20 mixture produced the most fruits. With or without the addition of fertilisers, there were no changes in leaf fluorescence across MSWC content.

Fruit fresh weight decreased in substrates with MSWC more than 5% when it came to fruit quality-related measures, although fruit dry matter content did not change across the groups of substrates. When varying MSWC contents were added to the soil, fruit size fluctuated, but the effects were more noticeable in fruit diameter (thicker fruits), as opposed to fruit length. In specifics, fruit length decreased when the substrate S: MSWC 60: 40 was applied, both fertigation ally and no derivational, compared to the control. Fruit diameter decreased when MSWC level in the soil exceeded 5%, however fertigation prevented this decline and kept fruit diameter constant throughout treatments. However, when fertiliser was added, potatoes' dry matter and visual health greatly improved in comparison to those that got MSWC.

## Conclusion

The evaluation of summertime human thermal comfort and heat stress in a greenhouse with arid climate. It was also looked at how the evaporative cooling of the greenhouse air affected worker comfort and heat stress. The key findings of this study can be summed up as follows.

I In uncooled greenhouses, workers would experience extreme heat and discomfort throughout the day, especially around midday; the risk of heat stress is anticipated. The most of the night, though, the workers would feel comfortable and secure from heat exhaustion.

(ii) During hot, bright days in a dry climate, efficient evaporative cooling of the greenhouse air can enhance worker comfort and lower heat stress levels the cooling [10] .

However, due to worries about the quantities of salt and metals in it, its application in agriculture has been questioned. MSWC production represents a significant recycling potential for many towns. Salinity appears to be the main barrier to using significant quantities of MSWC as a growth-media component. To prevent salt stress and negative impacts on plant growth, the MSWC rates must be regulated in accordance with the conductivity of the applied compost and the salt tolerance characteristic of the plant species. Thus, the substrate's addition of fertilizer mitigated the unfavorable effects of the elevated MSWC content and preserved fruit fresh weight. A substrate with an MSWC content of between 10 and 20 percent may promote plant development and fresh

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## Conflict of Interest

The author has no known conflict of interest associated with this paper.

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