Homogeneity of Temperature and Relative Humidity of Air in Greenhouse

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Abstract. The search for homogeneity of internal spatial distribution of a greenhouse temperature and relative humidity of air is fundamental to the effectiveness of the environment control and to the improvement of the productivity quality of plants. The homogeneity of the distribution of temperature and relative humidity of air was evaluated as a function of the quantity and location of wireless sensors in a 1,944 m² greenhouse, with lettuce cultivation in Ibiúna (SP, Brazil), with completely randomized design, three treatments (sensors) and 11 repetitions in time, at 9 h and 15 h. The Netherlands Organization for Environmental Certification determines acceptable differences of ± 0.75°C for temperature and ± 3% for relative humidity of air to consider an environment as homogeneous. We show that exist homogeneity, however its evaluation depends on the localization and quantity of sensors, considering the orientation of the greenhouse and the technologies applied to it.

Keywords: protected environment, relative humidity, spatial distribution, temperature, wireless sensor.

1. Introduction

Knowing the behavior of meteorological elements such as temperature and relative humidity of air in a greenhouse is essential to extract the benefits of protected cultivation. Monitoring indoor climate allows the verification of actual conditions of this environment, and the control, through systems and structures implemented, allows the achievement of the comfort conditions of growing plants. The adequate control of the microclimate, especially with respect to temperature and relative humidity of air, is one of the main tools for managing of operations in a greenhouse [1].

Temperature and relative humidity of air must be maintained within ranges considered optimum, minimum and maximum values, respectively, below and above which the plants do not develop properly. Rates of many biological processes are mainly affected by temperature [2] and the distribution of this element in the greenhouse is one of the factors that influence the uniformity of plant growth [3]. Therefore, the internal microclimate is important for the yield and quality of cultivated crops in this environment [4].

From the standpoint of ambience, the effect of air temperature is complex and depends on additional factors: it is the result of several simultaneous processes of energy transfer, which include radiation, ventilation and evapotranspiration [1], [5]. So many studies consider the temperature inside the greenhouse as uniform [6], [7].

The study of environmental heterogeneity presents itself as an important issue because of the impact that it has on the quality of plants [8] and, thus, seeks to homogeneous spatial distribution of these elements,
allowing the achievement of one of the major objectives of cultivation in protected environment: the development of plants in an uniform way and with good productive quality [9].

Climate measurements with the function of environment control should be carried out at representative points. The location of the sensors in the greenhouse is an important issue because its measures can be used for all control and you can get different values at different points of the internal environment [10]. Different sensors in a greenhouse may result in different temperatures over time, depending on the location in which they are installed [11]. Several studies, considering the homogeneity of the environment, use only one sensor at the geometric center of the environment as representative of the whole environment, which may be a mistake in the case of a heterogeneous environment. Other papers worked with the measurement of meteorological elements with sensor network spatially arranged and discussed the heterogeneity of the environment [1], [9], [12].

Although no values of acceptable differences for temperature and relative humidity have been set in the horizontal plane of the environment, defining its homogeneity, it’s recommended a limit of ± 2°C [13, cited by 9] and the Netherlands Organization for Environmental Certification [14, cited by 9] determines remain within ± 0.75°C; for relative humidity there are no established limits, but it is recommended ± 3% in the range of 70 to 90%.

Field measurements are essential to any improvement on the understanding of this complex system and focus on the amount and quality of data collected in the field, especially exploring spatial variations, it is necessary to develop and validate models of systems in protected environments based on real conditions [5].

The objective was to evaluate the homogeneity of the distribution of temperature and relative humidity of air as a function of the quantity and location of wireless sensors in a commercial greenhouse.

2. Material and Methods

The experiment was developed in a greenhouse, located in Ibiúna (São Paulo, Brazil) (latitude: 23° 23', longitude: 7° 47', altitude: 880 m), oriented east-west, measuring 45.0 m length and 43.2 m wide (floor area of 1,944 m²), ceiling height of 3.6 m and roof arched, with black shading screen with 70% of transmissivity, installed internally in the height, sides with mobile plastic and ventilation openings on the arches (Fig. 1a and Fig. 1b), with commercial cultivation of lettuce.

The internal environment of the greenhouse was monitored to evaluate the spatial homogeneity of temperature and relative humidity of air, for 11 consecutive days (February 4th to February 15th, 2013). The statistical design was completely randomized with three treatments (three sensors) and 11 repetitions in time (11 days) for evaluation of temperature and relative humidity, in two hours (9 and 15 h).

Fig. 1: North face of the greenhouse with sides with mobile plastic and natural ventilation on arches (a), windows on coverage and mobile internal shading (b) and NS101 sensor model used (c).

The meteorological variables were measured with a wireless sensor network (WSN), composed by three equipment model NS101 sensor (accurate to ± 0.3°C and ± 1.8%, respectively) (Fig. 1c), and a wireless gateway (model GS100-3G), with function to get information from NS101 and send the data via 3G mobile phone to the server. This wireless sensor network (WSN) uses the frequency of 915MHz (ISM - Industrial, Scientific and Medical band in Brazil), with Radiuinoc communication protocol. The polling mechanism is
the communication scheme between the gateway and the sensors, in which every 10 minutes the gateway requests the data of temperature and relative humidity for each sensor.

The three sensor nodes were placed 1.5 m above the floor, 11.5 m along the width relative to the south side, in three different positions along the length, and 11 m distant from each other in the same line (Fig. 2). The averages were calculated every 1 h. Analysis of variance was performed for times of 9 h and 15 h and, when significant, the means were compared by Tukey test (p > 0.05).

![Fig. 2: Horizontal position of the three sensors in internal environment of the greenhouse.](image)

3. Results and Discussion

Homogeneity in the distribution of meteorological elements such as temperature and relative humidity of air, within the internal environment of a greenhouse, can occur and is the goal of optimal control of systems and structures applied to this environment. However, the assessment of uniformity depends on a number of factors such as: the location and the amount of sensors, considering the position and orientation of the greenhouse, the season in which the measurement was performed and the technologies used to control this environment [15].

For the evaluation of the results, it was obtained the hourly averages of the three sensors, installed in three different positions in the greenhouse for the 11 days, and the measured meteorological elements temperature and relative humidity of air. The statistical analysis of data and the observation of the graphs (Fig. 3), no significant difference (p > 0.05) was found between the values of temperature and relative humidity measured in the three positions of the greenhouse.

![Fig. 3: Hourly averages of temperature and relative humidity of air measured on the three positions of the greenhouse.](image)
From the hourly average values for each sensor, were obtained the hourly averages between them. The difference between these results remained within ± 0.3°C for the air temperature and ± 3% for relative humidity (Fig. 4).

![Fig. 4: Differences between the average of the three sensors and the hourly average of each one of them for temperature and relative humidity of air.](image)

Although no values of acceptable differences for temperature and relative humidity have been set in the horizontal plane of the environment, defining its homogeneity, the Netherlands Organization for Environmental Certification [14, cited by 9] determines remain within ± 0.75°C for air temperature and ± 3% for relative humidity of air. Therefore, because of the values found in this work fit within these limits considered acceptable by the Netherlands Organization for Environmental Certification and because of no statistically significant differences were found in the comparison of the means, the internal environment could be characterized as homogeneous.

The heterogeneity of the environment depends, among other factors, the location of the sensors inside the greenhouse. In a study, a greenhouse was divided in four blocks of 360 m² each and distributed four sensors at different horizontal and vertical positions, near and distant of a tomato culture, obtaining differences of 1.51°C and 1.75%, between the points, for temperature and relative humidity, respectively [12]. Other study spaced a horizontal grid of 30 and 35 sensors, respectively, in greenhouses with floor areas of 5,100 m² and 9,792 m², with growing roses and naturally ventilated, and obtained maximum gradients of air temperature of 3.2°C and 3.5°C [1]. In greenhouses with floor areas above 6,000 m², with cultivation of gerbera, chamomile, cucumber and tomato, with ventilation system with automated control, were positioned 100 sensors in a horizontal grid, next to the crop canopy, and obtained differences from 1.0 to 3.4°C, between the means of sensors for air temperature and from 10 to 40% for relative humidity [9]. The proximity of the sensors to locations with higher incidence of radiation influence the temperature rise measured on that position. Likewise, the proximity of culture, nebulizers or a porous medium of an evaporative cooling system can also affect the results.

In this work, a greenhouse with lettuce cultivation was characterized, mainly, by the use of natural ventilation for renovation of the air and the management of the environment, through openings on the coverage and in front and side walls, and the use of shading screens that absorbed part of the incident radiation. Furthermore, the season, which covers the period studied, and the orientation of the greenhouse, both contribute to the incidence of solar radiation that occurs predominantly on the north and east faces. Therefore, the positions of the sensors near to the south side and distant of vegetable cultivation in the internal environment influenced the measuring of temperature and relative humidity of the air reflecting its homogeneity.

Changes in temperature and relative humidity can’t be obtained accurately with only one or a few sensors, because there are many natural variations in greenhouses, depending on the structures, systems and technologies applied on each case [9]. Although in this study the distance between the sensors (11 m) have been framed on the recommendation of the authors (33 m) and the number of sensors (three for 1,944 m²) have exceeded their recommendation (nine sensors by 10,000 m²), for detection of points with differences between temperatures and relative humidities, a greater number of sensors or a more comprehensive arrangement to evaluate the entire environment of the greenhouse, including the faces that receive higher incidence of radiation, is required.
4. Conclusions

The assessment of uniformity depends on a number of factors such as: the location and the amount of sensors, considering the position and orientation of the greenhouse, the season in which the measurement was performed and the technologies used to control that environment. Attention should be paid to the use of the sensor network in a greenhouse that should allow the monitoring and reflect on measures that better approximate to the real, by a convenient distribution of points.

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6. References


