Prediction the Spatial Air Temperature Distribution of an Experimental Greenhouse Using Geostatistical Methods

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Keywords: Kriging, variogram, evaporative cooling system, tomato crop

Abstract

Concerning the greenhouse environment, the ultimate goal of an investigation would be to determine the climatic parameters for all locations in the study area. Objective of the present study is to analyse the distribution of air temperature and air velocity of an experimental greenhouse with tomato crop, equipped with fan and pad evaporative cooling system, using geostatistical methods. The main aspects of geostatistics in terms of theoretical background for understanding spatial correlation models and kriging applications are presented. The most common variogram models were fitted to the experimental data sets obtained during summer period from an experimental greenhouse equipped with fan and pad evaporative cooling system. The Kriging approach was applied using the semivariograms corresponded to these data sets. Finally, the prediction maps of air temperature and air velocity were produced in different height levels inside the tomato crop canopy showing a great variability. Geostatistic analysis may be applied to determine not just optimal spatial predictions but also probabilities associated with risk-based analysis in order to improve the suitability and efficiency of climatic controls systems in greenhouses.

INTRODUCTION

Climate control in greenhouses is necessary for attaining high crop growth, yield and quality. Most control actions, mainly in Mediterranean greenhouses, are based on temperature and humidity measurements made at a representative point in greenhouse environment. Even in controls systems based on temperature integration concept, where fixed temperature bandwidths and integration intervals are commonly used, signals are obtained from specific regions in greenhouse. However, in order these control limits to be determined the spatial distribution of climatic parameters must be known, specially when high temperature gradients are occurred such as during ventilation and cooling processes. The drawback of the unknown spatial distribution of climatic parameters in greenhouse could be faced by experimentally analyzing the indoor climate or by analytical and simulation models, which have been widely used during last years (Mistriotis, 1997; Campen, 2002). Although both approaches are undoubtedly useful, they are time-consuming and some times extremely complicated.

Concerning the greenhouse environment, the ultimate goal of an investigation would be to determine the climatic parameters for all locations in the study area. As the most of these parameters are spatial correlated, they can be handled as regionalized variables. In order the values of these variables to be predicted, the knowledge of the prediction error or uncertainty in the prediction is quite essential. The easiest way to make predictions, when experimental data are available, is to use an average of the local data. But the only kind of data that are equally weighted are independent data. In addition, predictions that use an average are not optimum and they give over-optimistic estimates of averaging accuracy. Another way is to weight data according to the distance between locations. This idea is implemented by Geostatistical analysis which is based on using a

Proc. IS on Greensys2007
Eds.:S. De Pascale et al.
Acta Hort. 801, ISHS 2008

measurement of a regionalized variable at one location to gain information about values of the variable at another location.

Geostatistical methods rarely used in order to describe the distribution of climatic parameters in greenhouse. The Photosynthetically active radiation (PAR) was measured in a 9.15 x 9.15-m area of a 1006 x 915-cm gable roof greenhouse, across a grid of 40-cm intervals (Guertal and Elkins, 1996). In this study the spatial variation of PAR in the greenhouse was evaluated through geostatistical methods of semivariogram construction, providing a visual guide to the degree of spatial correlation of the variable. By this approach, the quantification of the distance at which variables cease to be spatially correlated, was determined showing that the greenhouse environment contained distinct zones of lowered values of PAR. The spatial variability of soil surface temperature conjugated with moisture content was examined by Al-Kayssi (2001) using semi-variograms and cross autocorrelation functions. The results showed that the spatial autoccorelation coefficient for temperature was significantly correlated for distances more than 8 m up to 15 m.

The objective of the present study is to apply the kriging correlation approach to the experimental data sets collected from an experimental greenhouse equipped with fan and pad evaporative cooling system. As the main disadvantage of this cooling method is the lack of uniformity of the climatic conditions, which expressed with large temperature and humidity gradients along the greenhouse, temperature maps according to kriging approach were produced for representative experimental sets in different horizontal levels inside the canopy and below of it.

MATERIALS AND METHOD

Experimental Greenhouse, Crop and Measurements

The experiments were carried out in a single-span, 8m x 15m greenhouse with an arched roof; it's orientation was 30º from North and its position was at: Latitude 40.54 N, Longitude: 22.99 E. The greenhouse had FRP (fiberglass reinforced plastic) sidewalls and an Aflex film roof (tetrafluoroethylene copolymer 60 microns, Asahi Glass Co, Japan). The gutter height was 2.6 m and the ridge height was 4.2 m. A cooling pad of width 6.0 m and height 1.0 m was positioned at the center of the north-wall, at 1.0 m above the ground. On the south wall, two fans were placed at 1.32 m above the ground.

Experiments were conducted two summer periods from August to September for 2006 and 2007 respectively. The greenhouse crop was tomato which cultivated using the common one stem technique (162 plants were transplanted at 3 June 2006 and 20 May 2007). During experiments the following measurements were recorded by a data logger system. Outside the greenhouse: air temperature, air humidity, air speed and direction at 10.0 m height from the ground, global and diffuse radiation. Inside the greenhouse: air temperature at 23-25 points, air humidity at 8 points in the same horizontal levels, solar radiation above the canopy, leaf wetness, soil moisture content and leaf temperature. Periodically, while the evaporative cooling system was operating, measurements were obtained with 2D Sonic anemometer at inside the greenhouse (19 points), at foreside of pad (15 points) and outside of fans (9 points). During the summer period of 2007 all the measurements were carried out in three different height levels of 0.3, 1.0 and 2.0 m above the ground and for three ventilation rates. Every week the leaf area index was recorded at 30 locations with a Sun Scan canopy analysis system (Delta-T Devices Ltd). In addition, pad water rate was measured by an integrated flow meter which was connected to the makeup water line to the pad storage tank. Finally, the operation time of the pump was recorder with an electrical on/off sensor.

Geostatistical Analysis

Geostatistics is a set of models and tools developed for statistical analysis of continuous data. These data can be measured at any location in space, but they are available in a limited number of sampled points (Journel and Huijbregts, 1978).

Geostatistics based on using a measurement of a regionalized variable $Z(x)$ at one location to obtain information about values of the variable at another location. All geostatistical approaches lie to the theory of regionalized random variables where the true measurement $z(x)$ is assumed to be the value of a random variable $Z(x)$. Associating a random variable $Z(x)$ with a true measurement $z(x)$ is done for the purpose of characterizing the degree of uncertainty in the quantity of interest at point x. If there is no actual measurement taken at x, then the values taken on by $Z(x)$ represent 'potential' measurements at x; that is, $Z(x)$ represents possible values that might be expected if a measurement were taken at x. Because there is uncertainty associated with $Z(x)$, it needs to be characterized by a probability distribution, defined by $P[Z(x) \leq c]$ where P denotes probability and c is any constant.

Regionalized random variables differ from classical (ordinary least-squares) regression models in that the residuals defined as the deviations of the regionalized random variable from its mean and denoted by $Z^*(\underline{x}) = Z(\underline{x}) - \mu(x)$ are related to one another, whereas the residuals in a regression model are generally assumed to be independent. Thus, in the regionalized random variable model, observed values of the residuals from sampled locations contain valuable information when predicting the value of $Z(x)$ at unsampled sites. The relationship among the residuals can be understood by examining the variogram, which is a tool that is widely used in geostatistics for modeling the degree of spatial dependence in a regionalized random variable.

One of the most important concepts of all geostatistical applications is the support of the regionalized random variable. The support of $Z(x)$ is the in situ geometric unit represented by an individual sample. For example, in air temperature distribution study, sample $Z(x)$ might represent the temperature of a volume which has a center at location x. Thus, even though $Z(x)$ is defined at a particular point, it is representative of a volume of the air. Changing the support of $Z(x)$ will usually change its probability distribution. The method called point, or punctual, kriging approach is designed to predict values of $Z(x)$ with the same support as the sample data. Actually Kriging is a spatial interpolation method which uses a weighted average of the available data assuming that the weights are functions of distance. Consider a regionalized random variable $Z(x)$, where x is a location in a two- dimensional study region R. Kriging is an interpolation algorithm that yields spatial predictions $Z(\underline{x})$ that are best, or optimal, in the sense that the mean squared predictor error is smallest among all predictors that are linear in the measurements.

RESULTS AND DISCUSSION

The experimental data sets obtained from specific points in greenhouse were analysed according to Kriging method using the commercial software Surfer® 8.0, Surfer (2002). By this approach temperature and air velocity maps were produced for different height levels. In Figure 1 the air temperature distribution was depicted while the fan and pad evaporative cooling system operated. The air temperature distribution at different height levels at the same moment is presented in Figure 2 showing that the cold air enters the greenhouse from the wet pad mainly passed below the crop canopy. This is the main reason for the formation of remarkable vertical gradients of the air temperature which could be reached even to 10ºC, Figure 3. Finally the vectors of air velocity magnitude and direction for the same ventilation rate produced by Kriging method, showing the influence of the crop to the reduction of the air velocity. An obvious advantage of the geostatistical approach is that the uncertainties aimed to the random variation of parameters related to the crop canopy (uniformity, plant's height) could be comprehended. Kriging application could provide a useful depiction of the greenhouse environment regarding climatic conditions.

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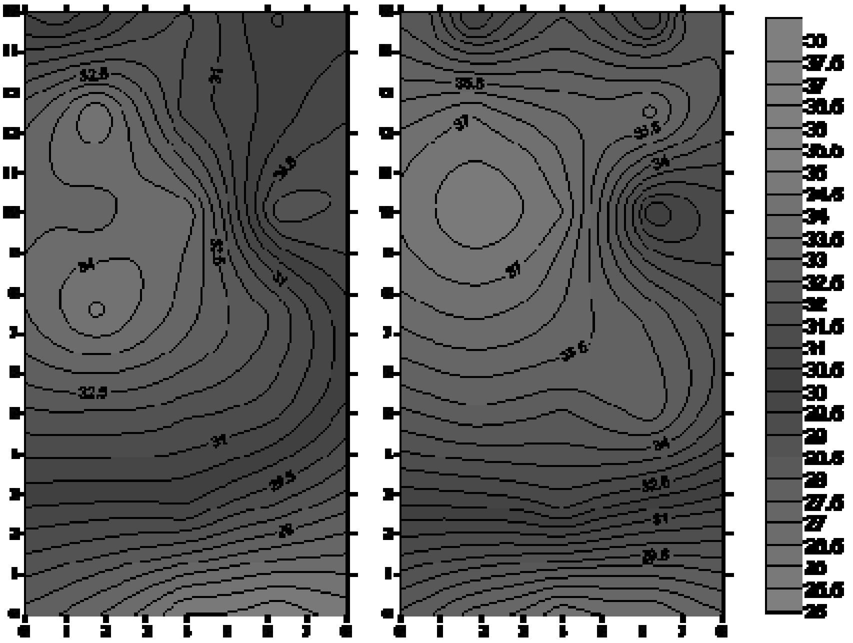
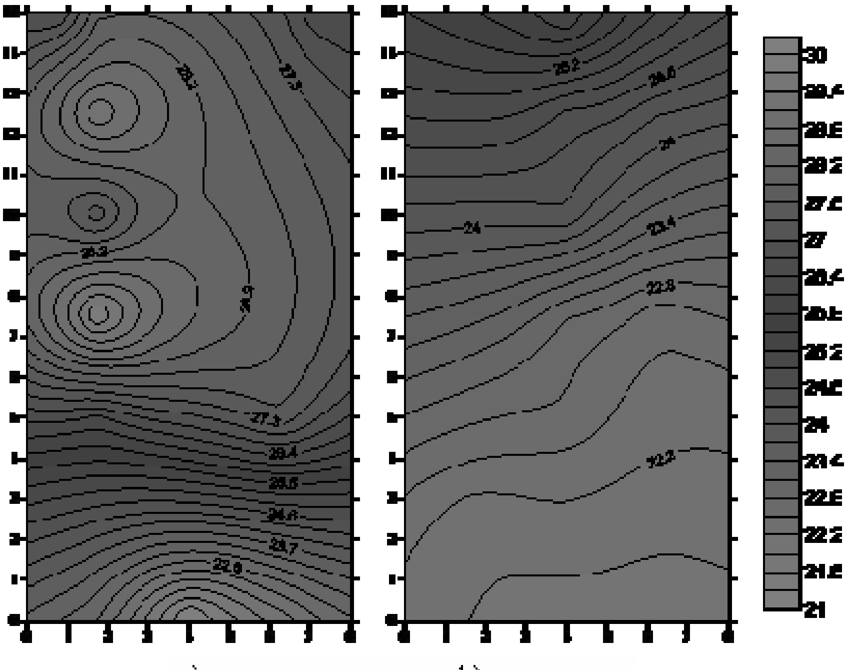
Figures



a) b)

Fig. 1. Air temperature distribution inside the greenhouse from pad (bottom of the figures) to fans (top of the figures), at 1.2 m above the ground as predicted using Kriging approach: a) at 12:10 pm and b) at 14:00 pm, (5/9/2006)



a) b)

Fig. 2. Air temperature distribution inside the greenhouse from pad (bottom of the figures) to fans (top of the figures) as predicted using Kriging approach: a) at 1.2 m above the ground and b) at 0.5 m above the ground (15/9/2006).

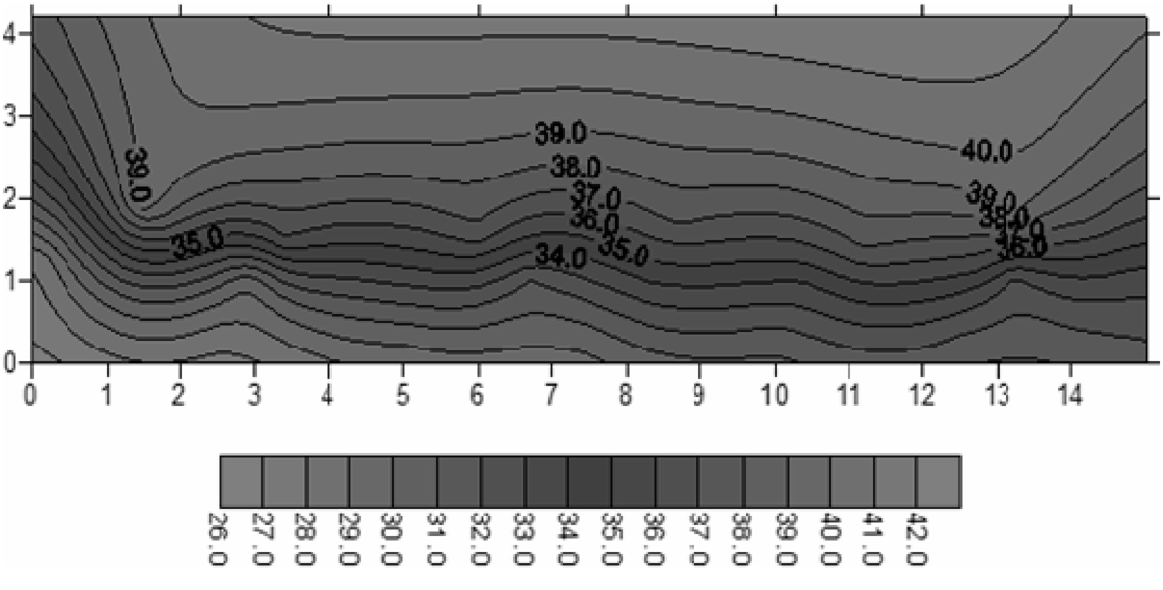
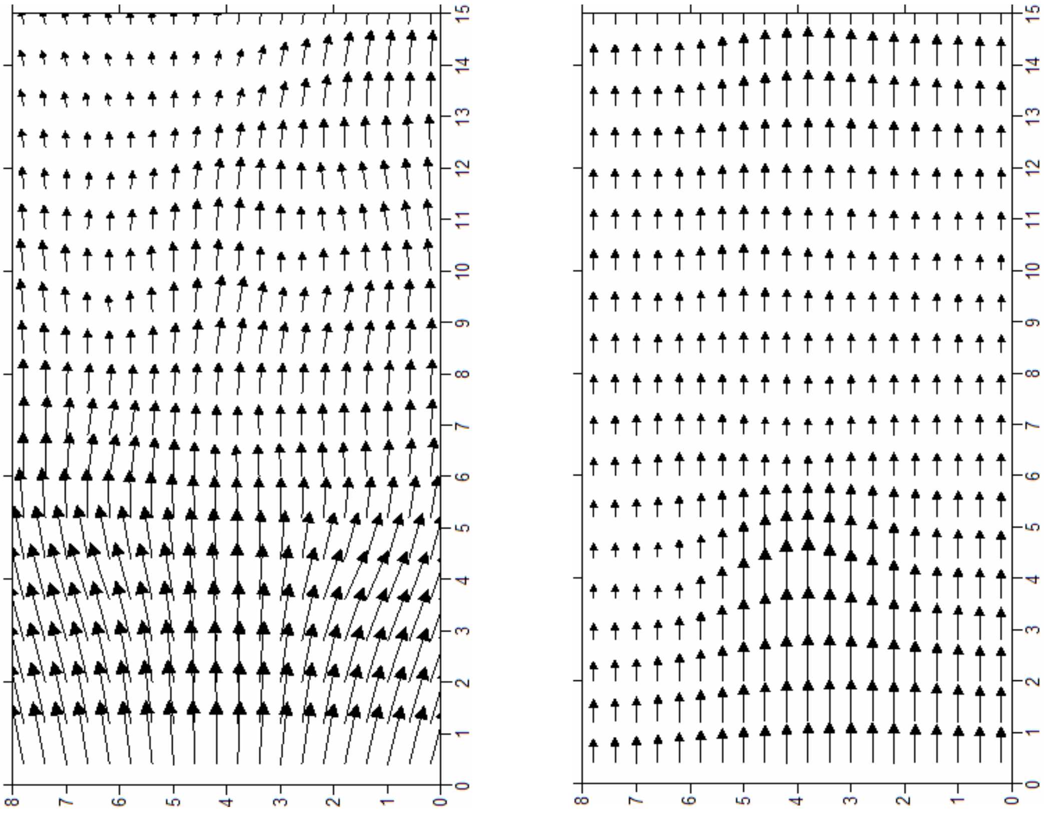


Fig. 3. Air temperature distribution in a vertical surface in the middle of the greenhouse as predicted using Kriging approach, (20/8/2007, 13:00).



a) b)

Fig. 4. Vectors of air velocity from pad to fans as predicted using Kriging approach: a) 0.3 m above the ground and b) 1.2 m above the ground.