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An Automatic Frost Protection System with Microsprinklers for Fruit Trees

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Abstract: In this study, the used computer program and the components of an automatic system developed to protect fruit trees from the spring late frosts by using microsprinklers are introduced. The performance of the system was tested in situ. In the system, ambient relative humidity, wind speed, air temperature, and bud temperatures are measured by sensors located about 1.5 meter above ground. A Data AcQuisition (DAQ) card inserted in a desktop computer is used to initiate or control the system by sending a signal to the selenoid valves. The LABVIEW package program was used to write and control the used software which is based on FROSTPRO model. The current phenological development stage of bud, the bud diameter, and the discharge rates of used microsprinkler are used as input to the system. The outputs of temperature sensors are converted into the interval of 0-10 V by transformers. The sensors were calibrated in situ by dipping them into cold water. The outputs were affected by the cable length and quality. Filters were designed and arithmetic averages per second of gained data were used to reduce fluctuations in the outputs.
Key words: Frost protection, mini sprinklers, automatic system, labview, peach tree

INTRODUCTION

Most fruit grower wory or uncomfortable during the nights or days of critic frosts events due to their desperations against this natural disaster. In Turkey, with changing from the year to year, the late spring frosts have made serious damages on fruit trees such as apricot, almond, peach, walnut, and citrus. The damages might be in the form of killing new spines, buds; decreases in the quality and quantity of yield; vulnerability to diseases, etc. These results cause price fluctuations in the market.

In addition, because of frost, some years the growers can not gain any income while covering extra costs for the maintenance of their gardens. According to the Tokat Provincial Directorate of Agricultural specialists, this extra cost is about 165 TL/da ($100/da) for the year of 2006. Öztekin (2008) analyzed the frost risks of peach gardens around Tokat city by using 35 years hourly temperature data and the dates of phenological development of J.H. Hale peach trees. The used model by the author produced frost damages in 13 years out of 35 (37%). For example the frost damages during the years of 2006 and 2010 seriously affected the province peach yield. Since the frost risk especially for radiation frosts is higher for the gardens close rivers or located at the bottom of valleys, some fruit growers, especially their gardens close to the Yeşilırmak river, have uprooted or removed the peach trees from their gardens and started to grow field crops at their gardens.

In Tokat province and as general in Turkey, there is no applied serious or effective frost protection system to protect fruit trees from frosts. However, Cittadini et al. (2006) indicated that in some valleys such as the lower valley of Chubut river in Argentina, the percentage of frost protected peach orchards by over-plant sprinkler irrigation is around 57%. In Tokat province, some farmers burn straws, hay, tire, etc. during frost times. In addition, as a frost protection method, some farmers are applying some kind of chemicals to delay bud development. Furthermore, until this year the Turkish government has not included completely the frost risk into the agricultural insurance coverage.

Among the one of the effective frost protection methods is sprinkler irrigation. The basis to protect the buds from frost by irrigation is to give the heat of water into buds when the water freezing on buds (80 cal/gram) as a thin water-ice film. Fruit growers seek low-cost, effective methods of freeze protection as alternatives to orchard heaters, wind machines, or overhead sprinkler irrigation (Rieger and Myers, 1990). Using water in the system can be cheap, not a pollutant for air and soil, and easy to be found at gardens. New approaches using this method consider to use water and energy wisely. Microsprinkler irrigation system can be one of these methods if it is used to irrigate just tree foliage or parts not the spaces between trees, and if the system is used intermittently in place of continuously. Rieger and Myers (1990) indicated that under calm conditions microsprinkler irrigation had maintained average bud temperature 5 ^{o}C above than those of nonirrigated trees. The authors also stated that microsprinkler and conventional overhead sprinkler systems provide protection via the same mechanism (i.e., release of sensible and latent heat of fusion of water), but installation and annual costs per unit land area are lower for microsprinklers (Harrison et al., 1983).

A frost protection project had been implemented at the Pennsylvania State University by Heinemann et al. (1990) to demonstrate the use of a computer to control sprinkling for frost protection. The authors stated that although this method could be implemented without the use of computer, growers could conserve water and reduce management time by using a computer to control the irrigation. Strawberry plants had been protected by this project. The authors also indicated that the same techniques could be applied to other small fruits, tree fruits, or vegetables.

Rieger and Myers (1990) evaluated the feasibility of using an over-tree microsprinkler irrigation system for spring freeze protection of 'Loring' peach trees. In their study, microsprinklers had been attached to the underside of polyethylene laterals 2.5 m above ground level and centered over the tree rows. The authors stated that microsprinkler irrigation had maintained average bud temperature above -2 ^{o}C and 2 to 5 ^{o}C above those of nonirrigated trees under calm conditions, but provided no protection under windy conditions. Furthermore, they indicated that the calculated water and energy consumption were reduced by at least 50% and 88%, respectively, by the microsprinkler system, compared to a typical overhead sprinkler system.

Koc et al. (2000) had implemented and tested an automated cycled overtree sprinkler irrigation system in a 0.4 ha dwarf apple orchard to protect apple buds from cold temperatures. The authors stated that the system reduced water usage compared to a more conventional approach of continuous sprinkling. The control scheme of their system is based on a system that monitors the environmental parameters (air temperature, wind speed, relative humidity) and bud temperatures, calculates the on and off times, and cycles the valve. In this study, it is stated that the average reduction in water during the three frost events tested was about 72% as compared to continuous water application using the same system.

At the Department of Biosystem Engineering of Agricultural Faculty of Gaziosmanpasa University, an automatic over-tree microsprinkler irrigation system for frost protection was developed. The developed system was set at a volunteer peach orchard owner since the year 2008. The general illustration of the system was presented by Öztekin et al. (2010). The purpose of this paper is to describe and present the developed computer program in Labview and electrical components used in the system.

MATERIALS and METHOD

As stated in the Introduction section, in Turkey the usage of effective frost protection systems in fruit growing is limited and the existed methods are not cheap, not environmentalist and their usage is difficult and they are not effective for whole garden. For these reasons, it is decided to develop an effective, cheap, user friendly, environmentalist, and automatic frost protection system by employing over-tree microsprinkler irrigation system. As well as the purpose of developing an automatic frost protection system for fruit trees, determining the effectiveness of three different microsprinkler nozzle diameters with the system for protection of peach buds from spring freezes were aimed.

In the system, ambient relative humidity, wind speed, air temperature, and bud temperatures were measured automatically by sensors located about 1.5 m above ground, and then these measured items were stored in the computer used in the system with required time interval (Figure 1). The control unit including the computer, selenoid valves, watermeters, centrifugal pump, hydrophore, convertors, power supply (0-30 Volt 5 Ampere), manual control system for selenoid valves, and so on was kept in a cage fabricated from steel sheet. This cage used as an instrument shed was located in the middle of the garden. For relative humidity, 0-10 V analog output ATR100-1 sensor with measuring interval of 1-100% rh; for wind speed, 0-10 V analog output sensor with measuring interval of 0-30 m/s; for air and bud temperatures, PT100 110-1000 mV output thermocouples with measuring interval of -200/+800 ^{o}C were used. To convert the resistances from thermocouples, the 0-5 V analog output-converters were included into the system. These all sensors were calibrated in situ, and then to produce the same data with the measured data within calibrated interval, their outputs were multiplied/divided by constants and then subtracted/added with some other constants. The data acquired from bud sensors were carried by multiple wired insulated cables within conduits buried about 40-50 cm underground. To determine the water usage effectiveness of three different diameter nozzles on frost protection of peach trees, the used water amounts by the microsprinklers are being measured by water meters.

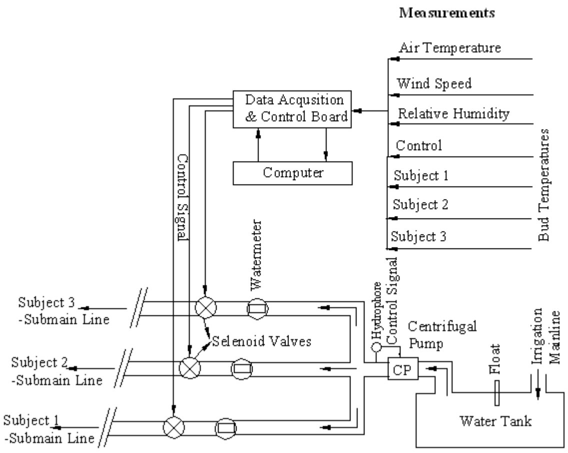

Figure 1. The components of the developed automatic mini irrigation system for frost control

The cables from all sensors were combined with a Data AcQuisition (DAQ) card (PCI 1711) junction cable (16 analog inputs, 8 digital 2 analog outputs). Then the data was conveyed to the DAQ card. The DAQ card inserted in a desktop computer was used to acquire the signals from the sensors and to control the system by sending signals to the selenoid valves.

The automatic irrigation control program was written in LABVIEW programming language (Version 8.5) by using the software by National Instrument Inc. During frost days/nights, the bud temperature sensors need to be inserted within the live buds by lanolin cream. In addition, the bud development stage, discharge rates for the used microsprinklers, the diameter of bud and output file name with its directory in the computer need to be entered in to the system throughout the computer screen. In addition to these manual inputs, the automatic measured (air temperature, wind speed, relative humidity, bud temperatures) and calculated items (date, time, irrigation rate, wet bulb temperature, adjusted crop temperature, on-off times, time to changes, maximum and minimum on-off times) by the system can be observed on the computer screen through the program written in LABVIEW. As well as working automatically, the system can also be turned on or closed off by interfering with the developed program from the computer screen. In addition, the on/off conditions of three different diameter nozzles can be seen on the screen.

The control algorithm of the developed program is based on FROSTPRO model (Perry, 1986). FROSTPRO requires the crop critical temperature, characteristic dimension (bud/blossom width), wind speed, relative humidity, and air temperature. The model determines the crop temperature by using the equations given by Barfield et al. (1992). In the developed program, the amount of water (rate) to be delivered and durations of on-off times are being determined using the principles given by Koc et al. (2000). The control algorithm of the program was given in Figure 2. As it can be seen from the control algorithm (Figure 2), the system is working in a continuous loop. In this loop, it is saving/writing some of the measured and calculated parameters of the system such as system date, time, bud and air temperatures, wind speed, relative humidity, and on-off conditions into a text file for every minute. The developed system can start to work when both the bud temperature is less than the adjusted critical bud temperature, and the wind speed is less than 6.7 m/s. Therefore, the system is not effective for the windy conditions (advective frost). Then, the system can run or wait for a while based on the calculated on or off times, respectively. The system stops when the bud temperature is greater

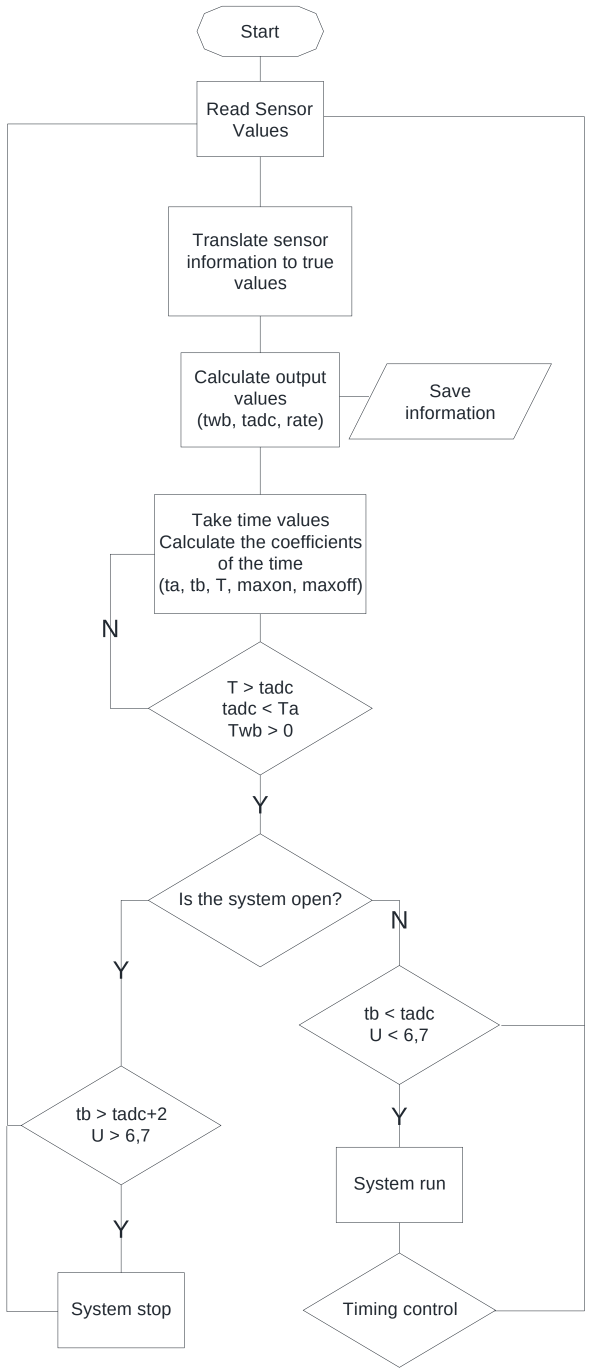

Figure 2. The control algorithm of the program

than 2 ^{o}C from the adjusted critical bud temperature. Based on the calculated on/off times, the system opens/closes the irrigation line by sending signals to the selenoid valves by DAQ card.

RESULTS and DISCUSSION

For the purpose of protecting peach trees from frost, the system was established in a garden of a voluntary farmer and tried to test for the years of 2008, 2009, and 2010. During the years of 2008 and 2009, any frost conditions at the orchard in which the system setup to be used to test and evaluate the effectiveness of the microsprinklers did not occur. During the year of 2010 frost events occurred during the nights of March 17, 18, 19, and 20. During these frost nights the system could not work properly due to problems such as failure of main electric power line; water seepages from the pump into the control cage that caused freezes in watermeters and selenoid valves; failure on automatic stopping mechanism between pump and hydrophore, failure of the fan used for the air temperature sensor, and so on. Solving these problems completely took days; therefore we could not test the system during these frost nights.

However the consistency of the measured parameters of the system was tested during two no-frost nights. A two-hour portion of these measurements belong to the March 19 of 2010 (Figure 3). These two-hour measurements were recorded for the hours between 16:35 and 18:35. From the temperature measurements, the high surge or fluctuations from the bud of third research subject (T3) can be noticed. In addition, the abnormality from the bud of the second subject (T2) can also be seen from Figure 3. While low pass filters were used for all bud and air temperatures, acquiring sensor data in high frequency, misconnections, cable length and quality, and noises from the components in the cage were thought as reasons causing this high surge and abnormality. In the year of 2011, employing arithmetic mean, acquiring data in low frequency interval reduced surge in the measured temperatures (Figure 4).

CONCLUSIONS

For fruit trees a frost protection system by using an automatic microirrigation system over trees was developed. LABVIEW programming language was used to compile and run the FROSTPRO based code

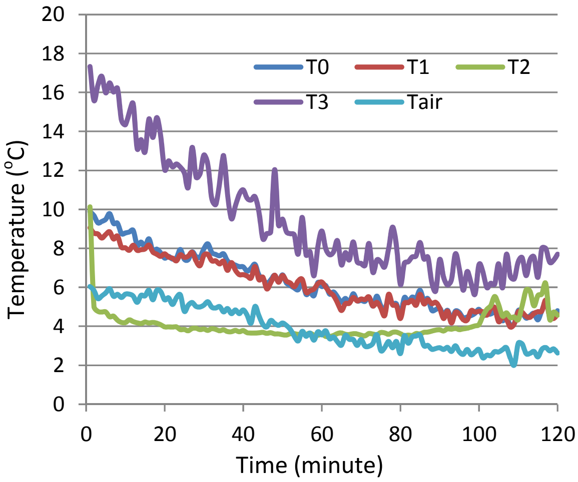

Figure 3. Measured temperatures by the sensors between the hours of 16:35 and 18:35 in March 19 of 2010

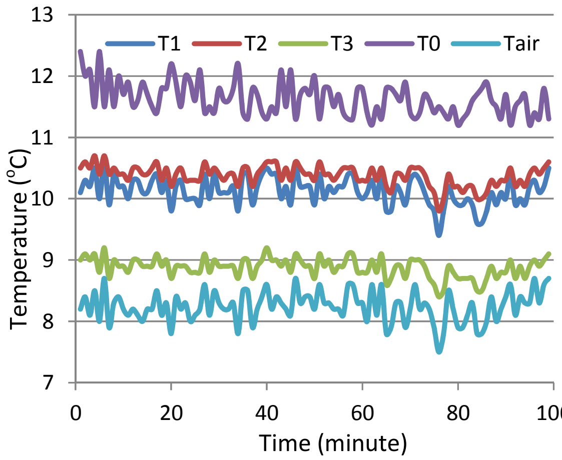

Figure 4. Measured temperatures by the sensors between the hours of 17:16 and 18:37 in April 25 of 2011

of frost protection system. Improvements in the system by testing it during more frost events are needed. While the developed system remained as work in the field for the years 2008, 2009, and 2010; the system could be tested only in the spring of 2010 with four night-frost events. To determine the frost effectiveness of the different nozzle sized sprinklers as used the research subject of this study, the system needs to be tested for more frost events.

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